Patent Landscape Report

Hydrogen fuel cells in transportation

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World Intellectual Property Organization
34, chemin des Colombettes, P.O. Box 18
CH-1211 Geneva 20, Switzerland

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Online resources: The electronic version of this report can be accessed at www.wipo.int/publications/en/details.jsp?id=4604. This webpage also includes datasets from the report.

Contact: patent.information@wipo.int

Key findings and insights

Transforming the transportation sector to put it on a Net Zero pathway will require a combination of technological innovation, government and corporate decision-making, and adapted customer behavior to all come together over the course of the next decade. Policy efforts across every transportation application will need to be rapidly developed and extended. Expanding international cooperation will be crucial in meeting the target of reducing greenhouse gas emissions by transportation, a sector responsible for almost 24 percent of direct carbon dioxide emissions from fuel combustion. With battery-powered electric transportation having grown over the last five years, the political momentum for hydrogen fuel cell transportation has gathered strength over the last two years. This WIPO Patent Landscape Report provides early observations on patenting activity in the field of hydrogen fuel cells in transportation. These observations are combined with online news, press releases and corporate financial reporting to obtain deeper insights into the future of transportation.

A third wave of patent filing is gaining momentum

There has been **a strong increase in patent filings since 2016, both in fuel cells in general and their application in transportation in particular**. A first wave of patent filings occurred in the mid-1980s, followed by a second around 2005, with a third wave starting around 2016. The patent search identified **52,433 patent filings** in the field of fuel cells that describe transportation applications, accounting for one-quarter of patent filings related to fuel cells in general. In all, **61 percent** (32,018 patent families) of these **included at least one granted patent**. **Half of this patent dataset** (26,449 patent families and utility models) were **considered active** at the time of the analysis in March 2022. A high number of fuel cell patents describe a specific use in transportation and this number is growing appreciably, thus highlighting the increasing importance of this particular market sector. (See the InfoBox below for information concerning the use of the terms "patent filings," "patent families" and "dataset" in this report.)

Patent filing activity is concentrated in just five jurisdictions which are also the biggest inventor locations

Inventions related to fuel cells in transportation were filed for patent protection across **88 patent offices**, with active patents present in 80 jurisdictions. While this suggests a wide spread of activity globally, a strong concentration of patents was located in just five jurisdictions. We found that 96 percent of the patent families identified included at least one patent application filed either in Japan, the United States of America (U.S.), China, the Republic of Korea, Germany, or at the European Patent Office (EP filings) or the World Intellectual Property Organization (WIPO) (administering the Patent Cooperation Treaty (PCT) and representing PCT filings). This suggests that the biggest production sites are striving to establish themselves in the five main industry regions, with markets starting locally before then spreading worldwide. The wide spread of activity also seems to signal a relatively easy access to the technology in general.

In total, 62 percent of the patent families identified filed for patent protection at only one patent office, with Japan and China each accounting for one-fifth of the patent applications filed in a single jurisdiction. By comparison, in the field of electric vehicles in general, national filings at a single office accounted for an even larger proportion (69 percent) of the total, whereas in the field of cancer research it was lower at 47 percent.

While patent filings stem from **inventors based in 85 jurisdictions**, the same five jurisdictions where the majority of filing activity is concentrated were also the **five biggest origins** for inventors, namely **China, Japan, the U.S., the Republic of Korea and Germany**, accounting for **89 percent of all patents in the field**.

Big players within the business have made a significant contribution to the patent landscape

The top 30 players in fuel cells in transport accounted for 40 percent of the patent dataset (21,152 of 52,433 patent families). This rather high concentration is similar to the what was observed in electric vehicles (top 30 players accounting for 43 percent of the dataset), and indicates the level of investment by market players in the field. Indeed, several of these players, namely, Toyota, Hyundai, VW Group, GM, Daimler, Bosch, Honda and Nissan, are active in nearly every transportation field. Moreover, it would seem their involvement encompasses not only specific end-products, but also the manufacturing of core elements.

New players are emerging in the patent landscape due to high financial investments

However, new players are already competing with the top-ranked players of recent years, and this may bring change to the list of top players in the future. In contrast to what is the situation in the field of electric vehicles, among the top ranking companies according to patent filing rate there are a number that are either not yet established market players – several of which are based in China – or smaller companies, especially in niche applications such as special vehicles. Patent filings and active patent portfolios are, however, dominated by the larger car companies in particular. Other top players across transportation applications other than road include companies active in aviation, shipbuilding and special vehicles, while automotive and battery suppliers also feature among the top applicants.

The patent landscape indicates a growing interest in automated production, while fuel cell recycling is also covered

Confirming an overall picture of a highly mature technology, alongside a high share of patents in direct transportation applications, we also see a growth in patents for automated production. Mass production has been addressed more frequently only recently, with a specific focus by players from China. At the same time, recycling is also starting to grow, even though patent filings are still low in number. In both areas, developments in patenting activity clearly indicate that, technology-wise, the level of readiness seems to be rather high.

The research community is playing a vital role in patenting aimed at overcoming technological challenges

There is only one university and research institution (the Chinese Academy of Sciences) among the top 30 patent applicants. However, patent filings from university and research institutions have grown in the last few years. Chinese universities have been remarkably active in the field, while there has also been related activity by universities in the U.S., the Republic of Korea, Japan and Europe. Besides patenting activity, some universities and research institutions exhibit a remarkably high level of collaborative activity, working together with industry, but also with other academic partners such as the French Alternative Energies and Atomic Energy Commission (CEA).

Fuel cells have achieved a high degree of technological maturity, with polymer electrolyte membrane fuels leading in patent filings

Fuel cells are a well-known technology with a high degree of maturity. There are several types of fuel cells, with polymer electrolyte (or proton exchange) membrane fuel cells (PEMFCs) leading in the patent dataset and appearing to be the most promising.

China is currently the top origin of patent filings related to hydrogen fuel cell in transportation

Patent filings in China have been incredibly strong in the last two to three years, either as the office of filing for local inventors or the office of subsequent patent filing for inventions originating from Japan, the U.S., the Republic of Korea and Germany. While China-based inventors account for a great portion of the data set, few Chinese companies feature among the top ranks in terms of overall active portfolio strength. Looking at the top corporate players in patent filing, they come from Japan, the Republic of Korea, Germany and the U.S. This may change quickly, if Chinese companies continue to patent at a rate identical to or higher than what has seen in the last few years.

Filings related to the road sector in transportation is the biggest category in the patent data, with other categories, particularly aviation and shipping, emerging

The dominant application for fuel cells and hydrogen in transportation is in road vehicles, including cars and trucks. Patent filings related to shipping, aviation, rail and special vehicles (i.e., commercial vehicles, including fork-lifts, airport tugs, tractors and dredgers, and various construction vehicles) only account for a small portion of the fuel cells in transportation dataset in comparison. Special vehicles are more or less the first type of fuel cell (FC) vehicle to enter a niche market (Energy.gov, 2018), while passenger cars may still be years away from making a large market entrance (see Figure 49, Roadmap).

An increased focus on battery-powered electric vehicles, with a possible niche in heavy-duty vehicles and bus applications in transport, extending a vehicle's range by additionally using fuel cells

Patent data indicates activity in hydrogen fuel cell vehicle technologies is strong, with corporations pouring huge investments into decarbonizing the sector. Because battery-powered electric vehicles appear to have a high degree of energy efficiency, as shown by studies in the last two years (e.g., Plötz, 2022), companies are focusing on penetrating the market with battery-powered electric vehicles to meet climate targets faster. Still, corporate statements and patent data provide evidence that heavy-duty vehicles is a potential market for hydrogen fuel cells, due to the required payload of these vehicles making the higher energy density of hydrogen a crucial factor and more advantageous in this respect than battery-powered electric vehicle solutions. This is highlighted by the examples shown in the section covering fuel cell application: personal and commercial road vehicles,, which are only a few of the numerous patents claiming fuel cells to be suitable for use in commercial vehicles to extend a vehicle's range.

Hydrogen fuel cells are expected to be a viable solution to aviation meeting climate targets

Hydrogen is the energy vector expected to play a key role in transforming aviation into a zero-carbon industry sector over the next two decades. Airbus, for instance, stated in a press release made in 2022 that hydrogen fuel cells is one of the most promising technologies on offer (Airbus, 2022). Airbus is the major aircraft manufacturer within the fuel cells for aviation field, with increasing patent filing activity since 2019, after a period of reduced activity in the preceding years. This same pattern can also be observed for other players, such as Raytheon.

Policies and corporate pledges to decarbonize supply chains and logistics are increasing patenting activity in shipping

Since companies are responsible for CO_2 emissions within their supply and logistics chains, they have pledged zero-carbon shipping by 2040 (see, for example, BBC, 2021) in order to push the heavily polluting shipping industry to decarbonize faster. With about 90 percent of the world's trade moving by sea, shipping transportation accounts for 3 percent of all global emissions. The patent field for shipping applications for fuel cells is comparable in size to the one for aviation and similarly slow in growth. Considering the long average service lifetime of ships, and the recent introduction of LNG (liquid natural gas) technology to fuel ships, this field is expected to continue have restrained growth, unlike, for example, fuel cells for special vehicles. However, it is worth noting that shipping companies such as Daewoo patent actively in the field of fuel cells for special vehicles, specifically in relation to their application within the harbor environment (e.g., up-/unloading, cranes, and so).

Hydrogen fuel cell trains as an alternative to diesel hybrid for decarbonizing rail networks

Hydrogen trains have several advantages over battery powered electric trains, in particular, they can refuel faster and travel further than their electric alternatives. It therefore comes as no surprise that Germany, Japan and the United Kingdom (U.K.) see hydrogen trains as central to their plans to decarbonize their national rail networks. They have already begun their deployment, with the first hydrogen train (by Alstrom) introduced on German railways in 2018 in partnership with Siemens Mobility, and the East Japan Railway planning to start testing hydrogen trains in Japan during March 2022.

The diffusion of hydrogen fuel cell technologies depends upon systemic drivers such as infrastructure, the availability of renewable energy and advances in battery technology

Although hydrogen can be produced from any number of energy sources, in an era of decarbonization, it is low carbon ("green") hydrogen that is needed to fuel transportation. Consequently, the availability of renewable energy is expected to play a critical role in hydrogen production, with several challenges lying ahead in meeting demand across the whole value chain (IRENA, 2022). Moreover, the infrastructure for the transportation and storing of hydrogen energy, as well as the fueling of cars, airplanes or ships, needs to be expanded and enhanced over the next number of years in order to ensure the diffusion of hydrogen fuel cell transportation applications into the market.

Technological progress in alternative electrification technologies, like for example future solid-state batteries, could lead to a doubling of driving range and a reduction in the gap separating these technologies from hydrogen fuel cells, which have the advantage of a high energy density through a higher capacity (IEEE Spectrum, 2021; EPO and IEA, 2020). When we compare the development in patenting activity in the field of fuel cells to that of solid-state batteries, we can see that the patent dataset of fuel cells is much bigger. But an increase in patents for solid-state batteries is about to gather pace, even though this has only become apparent in the last two years. This goes to indicate that, while technology-wise fuel cells have a high readiness level, the next generation of batteries to power the electrification of road transportation is already appearing over the horizon.

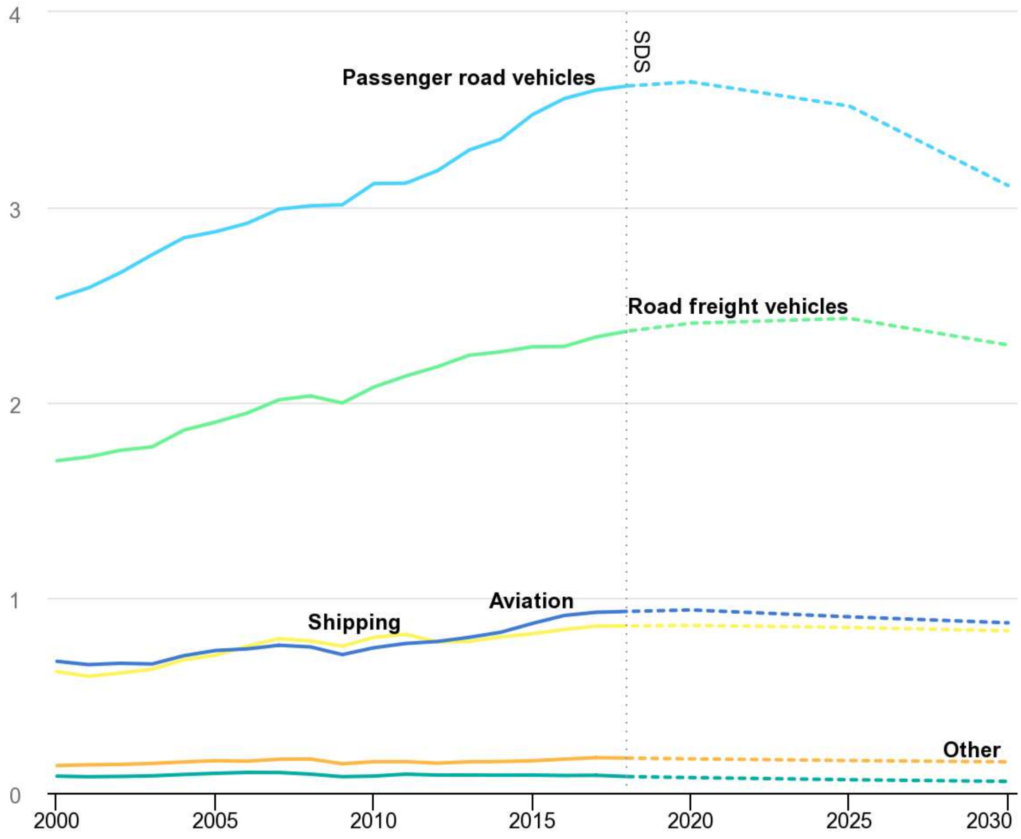
Introduction

Transport is essential to economic growth. However, in a carbon-based world, moving people and goods from place to place exacts a steep price in terms of pollution of the environment (Pradhan, 2019; World Bank, 2021).

Consider Europe alone. Transport-related greenhouse gas emissions within the European Union have increased steadily over the past 10 years, a trend that diverges significantly from other sectors during period. Preliminary estimates by the European Environment Agency (EEA) for 2020 indicate a substantial drop in transport emissions, because of decreased activity during the COVID-19 pandemic. Nevertheless, transportation is still likely to have been responsible for almost one-quarter (24 percent) of direct carbon dioxide (CO_2) emission from fuel combustion. Road transport – vehicles, trucks, buses and two-wheelers – accounts for nearly three-quarters of transport CO_2 emission, and, according to the EEA, emissions from aviation and shipping continue to rise (EEA, 2021).

Figure 1. **Transport sector CO_2 emissions by mode within the Sustainable Development Scenario (SDS), 2000–2030**

To achieve Net Zero goals, emissions by the road transportation sector - mainly passenger vehicles - will have to fall significantly.



Source: IEA (2021a).

Global momentum to achieve Net Zero greenhouse gas emissions is building more quickly than expected. Getting to that point will require unprecedented levels of technological innovation. A fast-rising number of companies and governments are committing to ambitious Net Zero goals and expect the necessary technologies and solutions to be available when needed.

Annual global emission of CO_2 equivalents now amounts to about 59 giga tonnes (UNEP, 2020). Reaching climate change goals may require a combination of existing and new technologies, novel business models, and markets. Some estimates, such as the P4 pathway laid down by the Intergovernmental Panel on Climate Change (IPCC), show that today's technologies have the potential to reduce global emissions by around two-thirds. A report by the International Energy Agency (IEA) estimates that most of the global reduction in CO_2 emissions through to 2030 is likely to be achieved through readily available technologies; while by 2050, almost half of the reduction will have been brought about by technologies currently at the demonstration or prototype phase (IEA, 2021c).

Electrifying the transportation system involves using a source of energy other than fossil fuels, including renewable sources, and offers numerous benefits (World Economic Forum, 2018). Besides battery-powered electric transportation, political momentum for hydrogen use continued to gather strength in 2020 and 2021. This is fundamental to the advancement of hydrogen technologies and markets.

In 2020, 10 governments adopted a hydrogen strategy: Canada (Natural Resources Canada, 2020), Chile (Ministerio de Energía, 2020), France (Ministère de la Transition écologique, 2020), Germany (Federal Ministry for Economic Affairs and Energy (BMWi), 2020), Netherlands (Governments of the Netherlands, 2020), Norway (Norwegian Ministry of Petroleum and Energy, 2020), Portugal (Direção-Geral de Energia e Geologia, 2020), the Russian Federation (Ministry of Energy, 2020), Spain (Miteco, 2020) and the European Union (European Commission, 2020). In 2021, four more countries adopted a hydrogen strategy: the Czech Republic (Ministry of Industry and Trade, 2021), Colombia (Ministerio de Minas y Energía, 2021), Hungary (Magyarország Kormánya, 2021) and the United Kingdom (U.K.) (Secretary of State for Business, Energy and Industrial Strategy, 2021). In addition, Poland and Italy have released hydrogen strategies for public consultation and more than 20 other countries have announced they are actively developing such a strategy of their own.

Europe is striving to become "the first climate-neutral continent" by 2050, aiming to have reduced net greenhouse gas emissions to 55 percent of what they were in 1990 by 2030 and become the world's leader in hydrogen technologies in the process (European Commission, 2021). To that end, it will focus on ramping up electrolyzer capacities in the coming years. The European Commission's hydrogen strategy aims to have created a multi-billion euro market by 2050, supporting up to 1 million jobs and helping achieve ambitious greenhouse gas reduction targets in sectors otherwise difficult to decarbonize.

The Republic of Korea, the U.S. and Japan have focused efforts on deploying passenger cars (IEA/AFC, 2021). They hold 90 percent of the inventory in this segment. However, this includes only a very small number of buses and commercial vehicles. Consequently, the U.S. Department of Energy recently announced new funding of around USD 160 million for fuel cell truck technologies and charging infrastructure (CSIS, 2021).

Meanwhile, China has adopted policies for fuel cell bus and commercial vehicle uptake, and now dominates global stocks in these segments. This trend is likely to continue, as the fuel cell vehicle subsidy policy adopted in 2020 aims to enhance the manufacturing capacities of China's fuel cell electric vehicle (FCEV) industry, with a focus on using fuel cells in medium- and heavy-duty commercial vehicles (S&P Global, 2020). China has initiated a four-year program in support of local governments researching hydrogen technology and developing an industry chain, intending a mass application of hydrogen within the transport sector by 2030 (Nikkei Asia, 2021).

The Republic of Korea's Hydrogen Economy Roadmap plans to have created a comprehensive hydrogen ecosystem in the country by 2040, while its New Deal (announced in 2020) sets the 2040 FCEV target at nearly 3 million, comprising 2.9 million domestically-manufactured FCEVs, 30,000 fuel cell trucks and 40,000 fuel cell buses (Ministry of Economy and Finance, 2020).

Japan sees the adoption of hydrogen as a major way to both decarbonize its economy and maintain industrial competitiveness (New Zealand Foreign Affairs and Trade, 2020). In 2017, Japan issued its Basic Hydrogen Strategy, becoming the first country in the world to adopt a national hydrogen framework. Hydrogen is among the 14 sectors identified under the Green Growth Strategy through Achieving Carbon Neutrality in 2050 that will be key to Japan's meeting its dual objective (Ministry of Economy, Trade and Industry, 2020). In June 2021, Japan updated its hydrogen strategy by introducing specific action plans to priority sectors, for example, mobility. Mobility targets included 200,000 FCEVs by 2025 and 800,000 by 2030, as well as 320 fueling stations by 2025 and 900 by 2030.

Adopting green hydrogen as a clean fuel is expected to stimulate new markets and new value chains, requiring regulatory frameworks to be adapted and certification schemes and standards defined in order to reduce barriers for interested stakeholders.

Motivation and methodology of the report

The topic selected for the present WIPO Patent Landscape Report reflects current expectation that the field of transportation will be transformed in the drive for Net Zero carbon emissions, and an understanding by the different stakeholders involved of the need to adapt their business, corporate and intellectual property (IP) strategies accordingly. The report's aim is to shed light on the current technology climate, its changing dynamics and the applications that hydrogen fuel cell technologies are expected to have in transport, and the impact this is likely to make in the coming years. At the same time, the report explores whether, because they form distinct markets, different transportation areas will have different implementation horizons.

The patent analysis was prepared using Lexis Nexis PatentSight covering patent documents filed or published from 1900 up until March 28, 2022. The patent search methodology incorporated several iterations of search queries related to hydrogen technologies, hydrogen technologies in transport, fuel cell technologies in transport, and searches related to specific transport areas, including road, truck, aviation, rail, shipping and special vehicles (for more detail on search queries, see "Patent searches" in the Annex). Search results were then normalized and cleaned to produce a final patent data set. Different technology fields based on predefined expert searches by EconSight complemented the search strategy.

Besides patent data, foresight principles were applied in the preparation of the report. Online news, press releases and quarterly financial reporting (for example earnings calls from corporations and organizations) for the period from 2018 to March 28, 2022, were taken from the foresight intelligence database by intuitive.AI. The foresight methodology (see, for example, Hines, 2006; Passing, 2017) included several iterations of search queries related to hydrogen fuel cell technologies in transportation and searches related to specific transportation areas, including road, truck, aviation, rail, shipping and special vehicles. The search results were then analyzed based on future-oriented statements from corporations and their CEOs, organizations and governments in order to derive an outlook and roadmap for hydrogen technologies in transport. An artificial intelligence (AI) algorithm and the proprietary technology of intuitive.AI has been employed to identify relevant future-oriented statements and to create a roadmap. Foresight indicators were applied and measured. They included publicly available future-oriented statements, the maturity of the technology, commercial viability, need for action and future drivers.

By combining patent data with relevant insights from the above-mentioned non-patent data, this Patent Landscape Report aims to provide a better understanding, in support of informed decision-making, of why and how technological advancements develop. In so doing, the report integrates societal, economic, environmental and political insights with the technological perspective of patent data.

The report first describes the use of hydrogen fuel cell technologies in transport. It then focuses on fuel cells, their history, types and application across different transportation areas. It analyzes the origins of inventions in the respective transport application sectors based on the inventor location, studying the evolution in patent filing activity over time by focusing on the last 20, and more specifically on the last five years, and measuring the filing activity of leading players in the field. The report also analyzes the filing activity and overall active patent portfolios of the main players and the protected markets. Finally, the report undertakes a deep analysis matching news and company statements (and the scientific literature referenced therein) with patent facts and examples in the specific application sectors, highlighting the benefit of combining many pieces of information into a comprehensible collection of data. These metrics allow for a clearer understanding of the current situation and inform a concluding discussion of the roadmap to the future.

InfoBox: What we do, what we count, how we count and why

In what follows, we analyze the patent landscape of hydrogen in transport from a multitude of perspectives. There are several general assumptions and methodologies that remain constant over the course of the analysis. Without specific mention in the text, we have applied the following general definitions and measures:

- Simple patent families are counted as a proxy for individual inventions. Most analysis refers to numbers of patent families (through a representative patent family member). The term “patent filings” is used interchangeably in the report with the terms “patent documents” and “patent families.” There is only one exception, namely visualizations relating to filings by patent office, referring to the individual patent applications (still counting each jurisdiction included among the patent family members once).
- Patent filings generally include both patents and utility models, without assessing their legal status.
- The first filing by a member of a patent family counts as the filing year. Each patent family is counted only once for the first filing in historic development analysis.
- Active patent portfolios: for this type of analysis, only patents and active patents (as in the INPADOC legal status definition) are counted. They are different from patent filings, since active patents are time-specific (active in a certain year) but highly relevant, especially when analyzing a company’s patent strength. Here the term “active patents” is used interchangeably with the terms “active patent documents” and “active patent families.”
- The origin of the inventor (inventor’s location or residence) is used as a proxy for the source of innovations. For patent documents with multiple inventors, we count the different locations listed and count the location for multiple inventors of the same origin once.

Hydrogen fuel cell technologies for the electrification of transport

General field overview, history, and global patent development of fuel cells

Hydrogen fuel cell technologies in transport: why hydrogen, and why fuel cells?

> *A fuel cell is a device that uses hydrogen (or hydrogen-rich fuel) and oxygen to create electricity. Fuel cells are more energy efficient than combustion engines and the hydrogen used to power them can come from a variety of sources. If pure hydrogen is used as a fuel, fuel cells emit only heat and water, eliminating concerns about air pollutants or greenhouse gases.*

Fuel cell technology is the only technology available for directly converting the chemical energy bound in hydrogen into electrical energy without producing greenhouse gases at the on-board conversion site. Therefore the primary focus for hydrogen in transportation is on the on-board generation of electrical energy, leading to the development of fuel cells for this purpose. The infrastructure, generation, quality, transport and availability of hydrogen are all highly relevant to the whole field, but outside the scope of the present study.

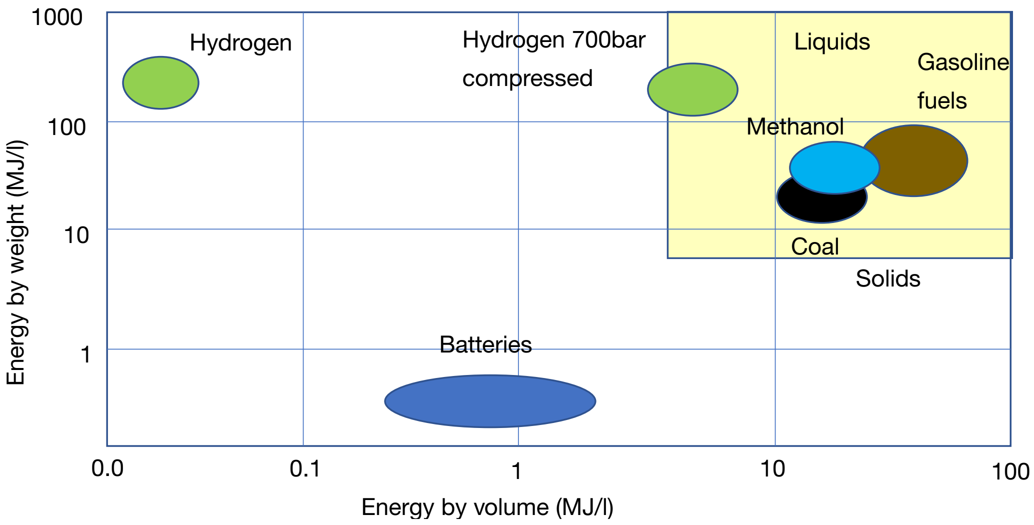
Fuel cells convert the energy stored in hydrogen to produce electrical power which can be used to drive electric motors such as those in cars. Hydrogen can be generated from renewable sources such as wind or solar energy by the electrolysis of water or by the steam reforming of organic, hydrogen-carrying molecules (for the production of so-called “green” or “blue” hydrogen, with several related issues, including high production costs, see IRENA, 2022). Hydrogen has a high chemical energy density by weight (the energy (megajoules) per kilogram is very high at 120 MJ/kg) comparable to, or even higher than, common liquid fuels like gasoline (46 MJ/kg) or methanol (22 MJ/kg), but crucially does not produce greenhouse gases when liberating electrical energy. This makes hydrogen an appealing candidate fuel of the future.

However, fuel cells can also run on alternative fuels, such as methanol, liquid ammonia or even natural gases, either directly or indirectly, when a reforming unit is attached to the fuel cell. Moreover, although gases such as hydrogen (or natural gas) possess very high energy by weight, they also have low energy by volume. Moreover, gases must be compressed into a liquid or absorbed into a solid (e.g., metal hydride) in order to be easily manageable, and increase weight by the addition of a necessary absorbing material. Another alternative is batteries. However, they are heavy and bulky in comparison and presently unable to deliver or store an equivalent amount of energy per kilogram or per liter (l). Therefore, the decarbonization of transport has practical as well as physical challenges that can be best met in a narrow range of physical conditions.

The energy density plot (energy/kg to energy/l) in Figure 2 demonstrates why liquid or solid fuels are the material of choice when it comes to energy carriers. Gasoline, kerosene, alcohols, even coal, all have quite a high energy content by weight and by volume. They carry all the energy needed within a relatively low weight (high energy content per kilogram or liter) and are fairly easy to handle, carry, refill and store. They are in the “sweet spot” area of the energy density plot, which makes them a favorable choice. Unfortunately, most produce CO_2 and other climate-relevant gases when energy is released. By contrast, hydrogen only produces water when used for energy release. When in a compressed and liquefied form (often called LH_2), or if converted to methanol or ammonia, hydrogen can have an energy density comparable to standard fuels.

Hydrogen gas carries a lot of energy by weight, but being a gas has only low energy by volume. When liquified, it carries 8 MJ/l compared to 32 MJ/l for gasoline. However, LH_2 carries more energy by weight and by volume than do batteries and therefore able to extend the range of vehicles beyond what is currently achievable using batteries of the same weight. Batteries will always be the heavier of the two by energy stored, even when the weight of the storage tanks is added to the weight of the LH_2. The overall weight of the energy carrier is a major consideration for any vehicle, but for freight – especially for air transport – it is a huge and decisive cost factor. Consequently, batteries have a limited application range in transport that includes mostly passenger vehicles. Aside from the discussion as to which fuel best suits the many transport options, the only one potentially available for full-range decarbonization, especially of commercial transport, is “green” hydrogen in either of two forms: directly in fuel cells, supported by batteries, or converted into methanol, ammonia or another gas.

Figure 2. **Energy density plot – energy by weight versus energy by volume.**
The “sweet spot” lies in the upper right of the density plot, where solids (coal) and liquids (gasoline, methanol and so on) are to be found, since these are manageable at room temperature and contain a lot of pure energy per kilogram and per liter.

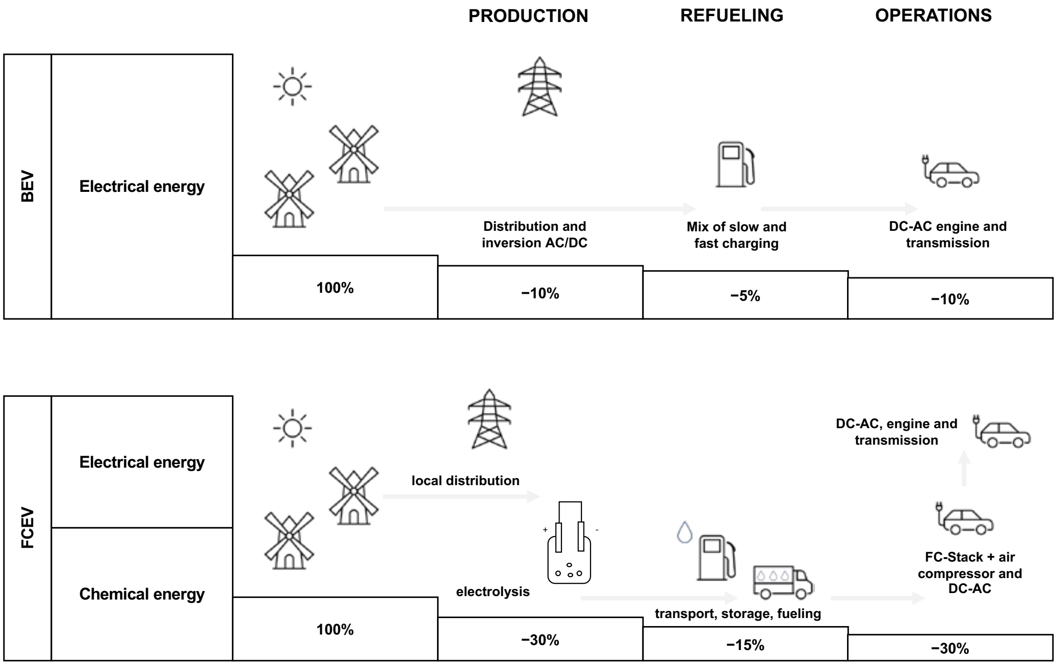


Source: Adapted from Choon *et al.* (2018).

Although the energy density of hydrogen is very high and it therefore has advantages for various application fields in transport, the entire life cycle or system from production to usage of hydrogenneeds to be considered (e.g., Plötz, 2022). While fuel cells produce electricity from hydrogen at the site where it is needed, there is a system chain attached relating to hydrogen in transportation, see Figure 3. Hydrogen must be generated, for example by the electrolysis of water using wind or solar energy, giving rise to related discussions on producing green hydrogen from renewable power (IRENA, 2018) and of connected issues (IRENA, 2019). Hydrogen must be further purified, stored and transported through pipelines; filled and refilled in a 700-bar pressurized container or converted into metal hydride or methanol; and liberated, reformed or released again through valves. It can be used as a carrier gas in airships or simply burned in motors or rockets. A full infrastructure is required for the provision of hydrogen. And in its operations, processes like converting chemical energy to electrical energy are needed for the transmission of the vehicle. All this is associated with energy losses during the production, refueling and operation phases. Comparison between FCs and EVs shows the efficiency of fuel cell technologies to be lower than for battery powered vehicles.

Figure 3. Life cycle efficiency of hydrogen fuel cell-powered vehicles compared to battery-powered vehicles

Battery-powered vehicles are much more efficient than hydrogen fuel cell-powered vehicles when looking at their life cycle efficiency. Seventy five percent of the produced energy in BEVs reaches the wheels as opposed to 25 percent in hydrogen fuel-cell powered vehicles.



Source: Adapted from Traton (2022).
Note: EV is electric vehicle; FCEV is fuel cell electric vehicle.

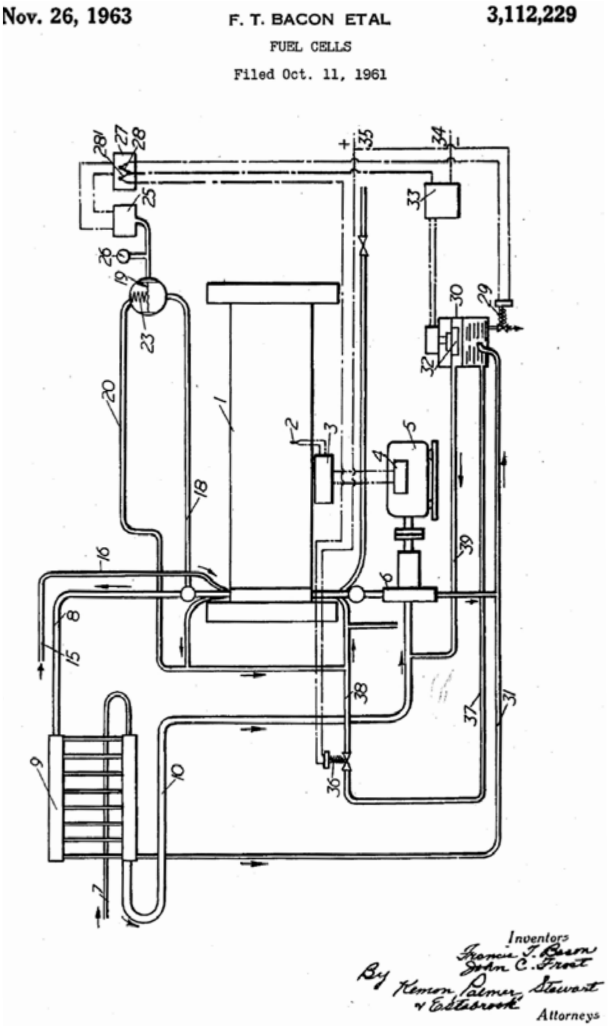
However, for this report, we have chosen not to analyze all the technologies related to hydrogen in transport, but focus instead on the conversion of hydrogen into electricity for the electrification of transport using fuel cells.

Fuel cell history

The fuel cell was invented in principle in the 1800s, possibly by Christian Friedrich Schönbein in 1838 or by William Robert Grove in 1839. It was not until the 1960s, however, that fuel cells were first used commercially in NASA's space project Gemini, which ran from 1962 to 1966 (Hacker and Grimwood, 1977).

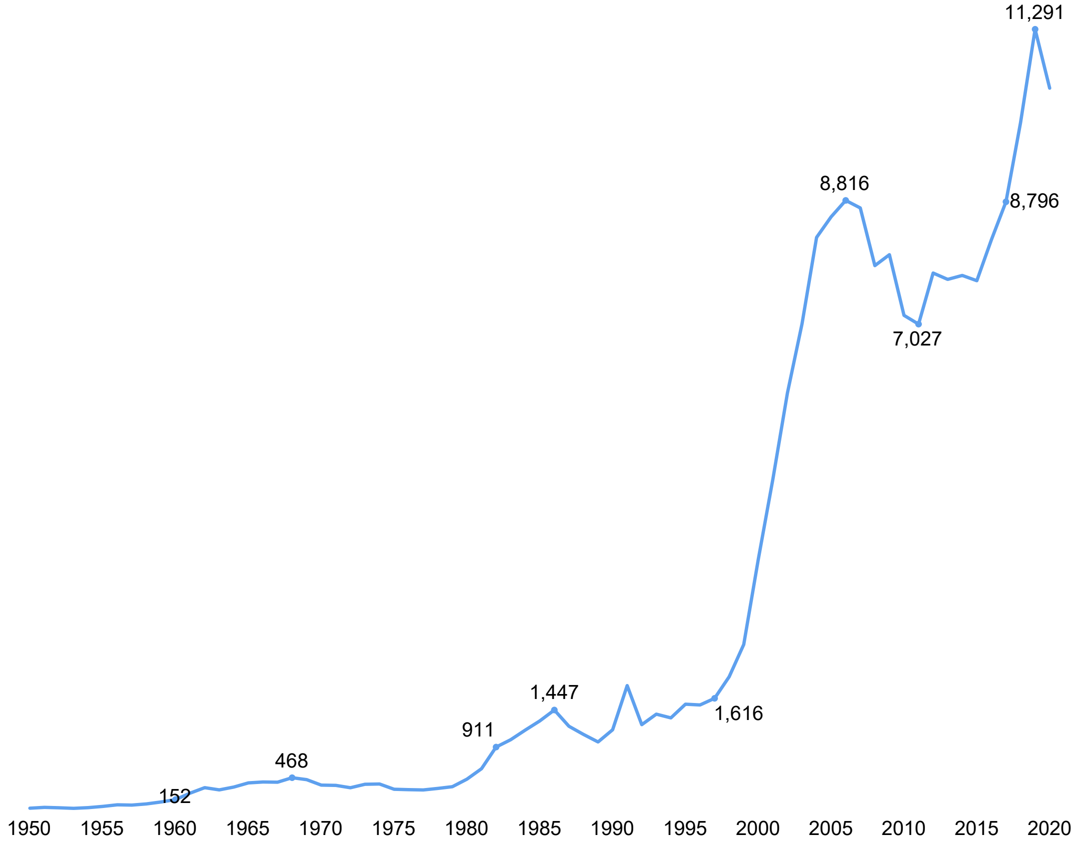
Figure 4. **Drawing from U.S. Patent US3112229, “Fuel Cell,” by Inventor Francis T. Bacon, filed in 1961 and published in 1963.**

Francis Bacon was one of the inventors of the modern fuel cell which was adopted by NASA in the 1960s.



While the Gemini project marked the first phase of patent applications, there have been several similar peaks in innovation since, as suggested by the patent filings over time (Figure 5). In 1991, for example, Roger Billings developed the first fuel cell car (Billings and Sanchez, 1995; Billings, n.d.). But it was not until 2001 that there was any great increase in fuel cell innovation activity.

Figure 5. **Patent filings in the field of fuel cells by year of filing (1950–2020).**
The first measurable increase took place in the 1960s in relation to NASA's Gemini project and the next in the mid-1980s and around 1991, when the first fuel cells were integrated into cars. The sharp increase in patent filings related to fuel cells that occurred from 2000 to 2005 was followed by a decrease, before a new upswing began in 2016 and peaked in 2019.

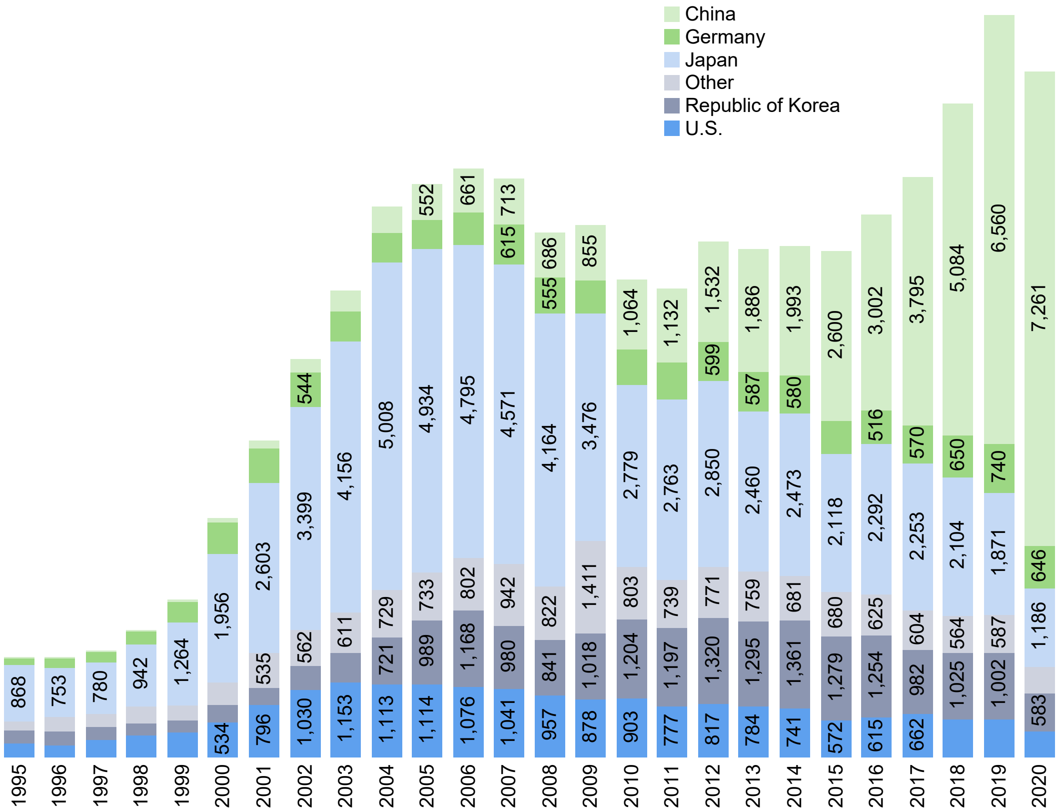


Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: There is an average 18-month delay between patent filing and publication. 2019 is the last year for which complete data are available.

Interestingly, a breakdown of filings by inventors' origins shows the surge in patents during the years 2000–2005 originating from inventors in Japan, followed by inventors in the U.S. and Germany. Not until a few years later did inventors, first in the Republic of Korea and then in China, close the gap (Figure 6).

Figure 6. Number of patent filings by the five key inventor locations.

Japanese inventors contributed heavily to the first major surge in patent filings related to fuel cells (2000–2005) and Chinese inventors to the second (2016–2020).



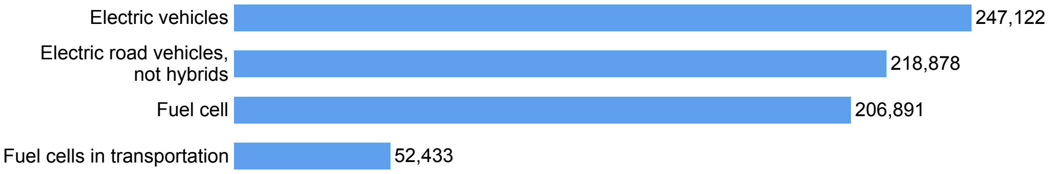
Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: “Others” refers to all other inventor locations. There is an average 18-month delay between patent filing and publication. 2019 is the last year for which complete data are available.

Patent filing activity shows that after an initial surge of patents beginning in 2000 and peaking in 2005 innovation activity slowed down until around 2013, when inventors based in China started filing patents in fuel cells more strongly. Since 2015, China has dominated filings in the field. The top five inventor origins account for most of the patenting activity relating to fuel cells, contributing 89 percent of the data set, with few contributions from other jurisdictions, such as France, the U.K., Canada and Italy.

There are more patent filings related to electric vehicles than for fuel cells in general, with one-quarter of the latter referring to transportation applications.

Figure 7. **Number of patent families in the fields of fuel cells and fuel cells in transportation compared to electric vehicles (EVs) and to EVs excluding hybrid vehicles.**

Fuel cells in transportation account for 25 percent of the total fuel cells dataset, while patent filings related to EVs excluding hybrids are nearly at the same level as those for fuel cells.



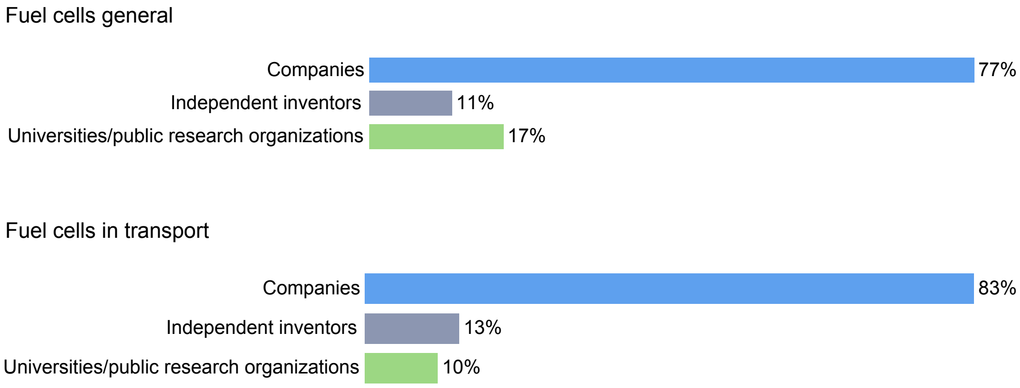
Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.

Looking at overall trends within the field of fuel cells, patent applications referring to fuel cell applications in transportation account for one-quarter of filings (for other application fields, see IP Australia, 2021). Compared to the 247,122 patent filings in the field of electric vehicles, fuel cells is in general lower, with close to 207,000 filings (transport even lesser in transportation). Related active portfolios are roughly half the number of the patent filing counts, with the field of fuel cells in transport having a slightly lower active portfolio size.

Patenting filing activity by applicant profile

Figure 8. **Contribution of different patent applicant profiles to the patent data sets related to fuel cells (in general) versus fuel cells in transport.**

Companies dominate, contributing around 80 percent to both patent data sets, whereas universities and research institutions account for less than 20 percent of patent filings.



Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.

In terms of applicant profiles, companies dominate the field of fuel cells, accounting for about 80 percent of related filings – both in the very application-specific fuel cells in the transportation field, but also fuel cells in general, with universities and research institutions accounting for less than 20 percent of the dataset. Nevertheless, filings from academic patent applicants have grown in the last few years. (More information can be found under "Top 20 universities and research institutes in the field.")

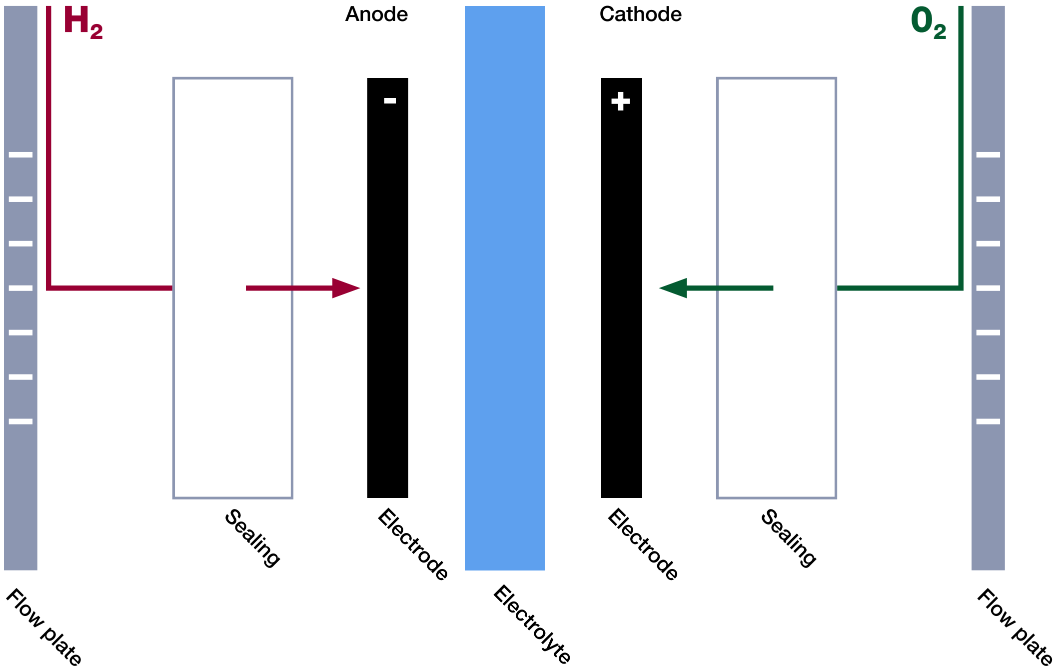
Fuel cell technologies

General overview

In every fuel cell concept, fuel (mainly hydrogen) is made to react with oxygen (typically from air) to form water. Differences in type of cell are mainly ascribable to the membrane concept and the electrodes.

Basic fuel cell principle and setup

Figure 9. **The basic fuel cell comprises two flow or bipolar plates and two catalyst-loaded electrodes either side of a central electrolyte.**
Hydrogen and oxygen flow into the reaction zone and react to form water when liberating chemical energy. The electrical energy produced is then usually extracted via the bipolar plates.

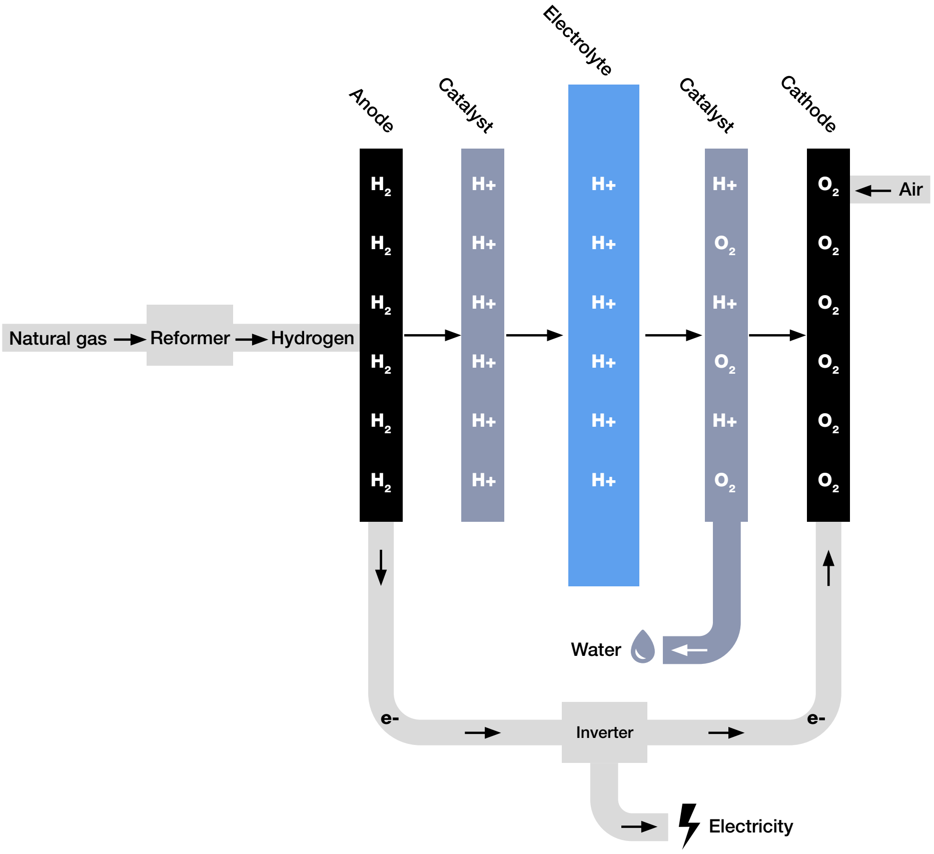


Source: adapted De Bruijn (2005).

A basic fuel cell design is common to all types of fuel cell (Figure 9). It comprises a membrane, two electrodes that usually carry catalysts, plus a bipolar plate on either side responsible for gas flow and electric current collection.

Fuel cell reaction schematic and main parts of a fuel cell

Figure 10. **Main parts of a fuel cell.**
Bipolar plates are removed for ease of reading. Reformers are added to highlight the option of running on different fuels.

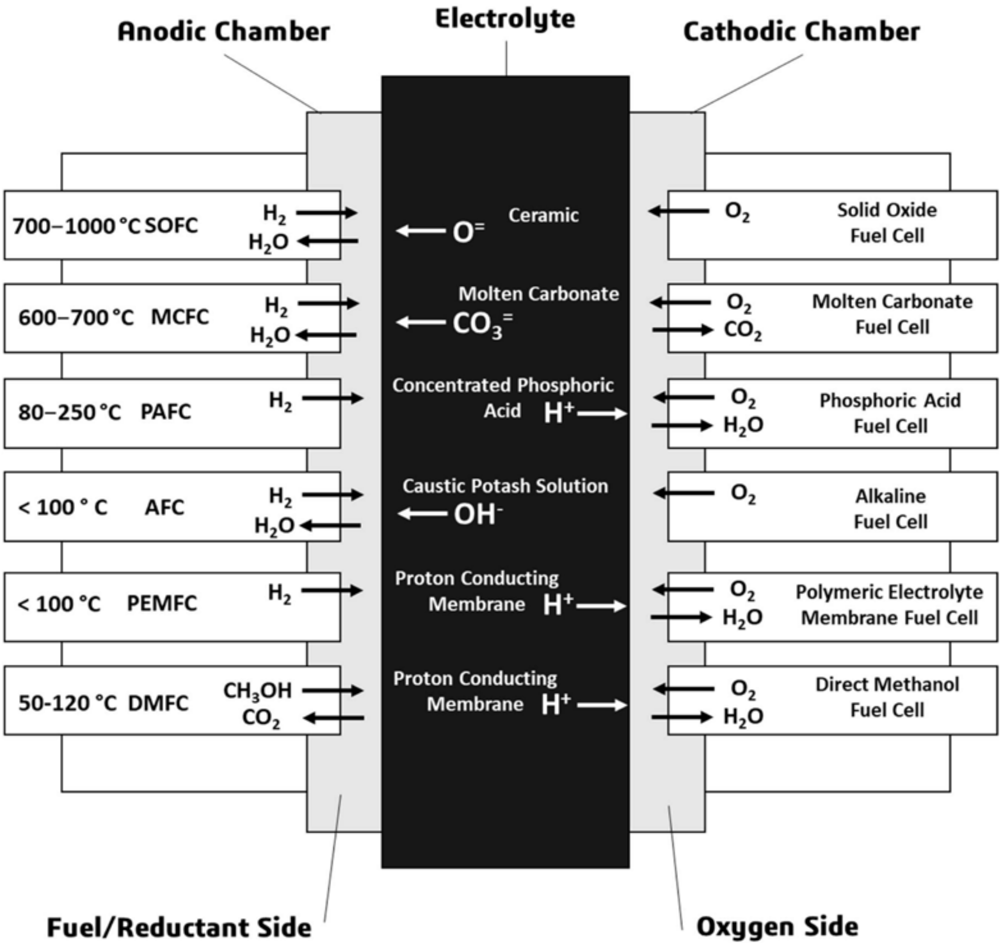


Source: adapted De Bruijn (2005).

Over the course of more than 150 years of fuel cell development many variants have been developed. The most relevant fuel cell concepts nowadays are polymer electrolyte membrane fuel cells (PEMFCs) and solid oxide fuel cells (SOFCs), followed by phosphoric acid fuel cells (PAFCs) and molten carbonate fuel cells (MCFCs). Whereas the majority of fuel cells work using hydrogen, some can work either directly or indirectly using other fuels, such as methanol, liquid ammonia, natural gas or even diesel. In direct methanol or direct ammonia fuel cells (DMFCs, DAFCs), the fuel is used in the cell. When the fuel cells work indirectly, the fuel cell still works on hydrogen, but there is a reformer or cracker installed in front of the fuel cell that converts the fuel into hydrogen just prior to use. Figure 11 illustrates the differences between variants of the most common fuel cell types.

Methodology of the most common fuel cell variants

Figure 11. **Fuel cell technology overview showing the most common fuel cell variants, the membrane type, temperature range and the chemical reaction involved.**
The general principle is common to all fuel cells. The two main differences are the electrolyte and the reaction conditions. The most common fuel cell type is PEMFC, which operates at a moderate temperature range and uses a polymeric proton conducting membrane. Other variants operate at much higher temperatures and use different electrolyte materials, which affects the whole fuel cell design.

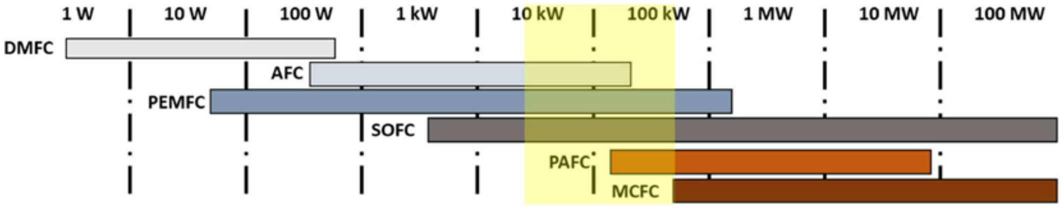


Source: Cigolotti *et al.* (2021).

Different types of fuel cells have different power ranges. This limits their scope of application. Some typical power ranges are: 50–100 W for laptop computers or portable small units; 1–5 kW for homes; 50–125 kW for road transport vehicles, with cars around 50–100 kW; and trains between 50 and 125 kW (Institution of Mechanical Engineers, 2018); and 1–200 MW or more for central power generation. The best fits for transport are therefore PEMFC and SOFC, while PAFC and MCFC, and also SOFC, are better suited to power plants (mostly stationary, but also in large ships) (U.S. Department of Energy Hydrogen Program, 2006; Institution of Mechanical Engineers, 2018).

Power range of fuel cell variants

Figure 12. Common types of fuel cells and their power application range.
The yellow range is the typical transport area. Road transport usually requires 50–125 kW, special vehicles 100–160 kW and trains and ships 50–200 kW, possibly more.



Source: Cigolotti *et al.* (2021).
Note : DMFC is direct methanol fuel cell; AFC is alkaline fuel cell; PEMFC is polymer electrolyte membrane fuel cell; SOFC is solid oxide fuel cell; PAFC is phosphoric acid fuel cell; MCFC is molten carbonate fuel cell.

Polymer electrolyte or proton exchange membrane fuel cells

PEMFCs are currently the most common fuel cell technology, invented around 1960 by Thomas Grubb and Leonard Niedrach. A proton exchange membrane fuel cell transforms the chemical energy liberated during the electrochemical reaction of hydrogen and oxygen to electrical energy, as opposed to the direct combustion of hydrogen and oxygen gases to produce thermal energy. It is currently the most promising fuel cell design for transport for several reasons: it operates at a relatively low temperature range of between 100°–180°C; can quickly vary its output; is smaller in volume and size than most other types; has a good availability of membranes (e.g., NAFION or CELTEC, produced in large volumes); and has a straightforward production process that can operate at a large scale. In order to function, the membranes in PEMFCs must be able to conduct hydrogen ions (protons); however, this does require rather expensive platinum catalysts (Pollet *et al.*, 2016).

Solid oxide fuel cells

SOFCs are characterized by their electrolyte material, either a solid oxide or ceramic electrolyte. Known about since the early twentieth century, a SOFC uses the most simple of fuel cell designs – just gas and solids. Among the advantages of this class of fuel cell are high combined heat and power efficiency, long-term stability, fuel flexibility, low emissions and relatively low cost. The biggest disadvantage is the high operating temperature (500–1000°C), which requires longer start-up times and results in mechanical and chemical compatibility issues. SOFCs were used in cars during the 1990s, but have since been replaced by PEMFCs. They are still under intensive investigation for several transport applications, especially shipping and rail.

Direct methanol or liquid ammonia fuel cells and reformer technology

Fuel cells can convert chemical energy into electrical energy. They most often use hydrogen directly and make it react with oxygen (such as from air) in order to liberate stored energy. However, fuel cells can also work with other fuels, either directly, such as in DMFCs (first developed in 1955), or indirectly via a reformer. **Methanol** is the most often discussed alternative fuel for fuel cells (Sun and Sun, 2020).

Reforming or steam reforming (since it works with vaporizable chemical products only) is a very old process, invented by Carl Bosch around 1920 (Haber–Bosch process) in the search for better access to hydrogen for the production of ammonia (mainly for fertilizer). In reforming, molecules carrying hydrogen, such as methane, are converted into hydrogen (and by-products such as carbon monoxide). Reforming is still the largest industrial process for generating hydrogen. As this process produces huge amounts of carbon dioxide, it is of the utmost importance as to which sources of hydrogen are employed in the process (Gielen *et al.*, 2019).

In the case of **liquid ammonia**, ammonia crackers liberate stored hydrogen via a catalytic cleavage process (Faleschini *et al.*, 2011). Liquid ammonia's role in the hydrogen industry was first discussed back in 2006 (U.S. Department of Energy, 2006), but seems to have attracted a lot more interest recently (Jeerh *et al.*, 2020), especially as ammonia can be liquified far more easily than hydrogen (ammonia needs only –33°C to liquify as opposed to 253°C for hydrogen).

Finally, **natural gases** can also be successfully reformed into hydrogen. However, because CO_2 is produced as by-product, this fuel is only an option for existing installations such as those on board ships, where liquified natural gas (LNG) is a fairly common fuel.

Besides the large industrial applications for reforming and the ammonia cracking process, it is not unusual today to find on-site mobile and small reformer and cracker units directly attached to fuel cells. These smaller units convert methanol, liquid ammonia and several other vaporizable materials directly into hydrogen (even natural gas or diesel can be used for this purpose). The biggest problem in both cases is impurities poisoning the fuel cell. Proper working, reformer-equipped fuel cells can therefore serve as a bridge between the ease of handling of liquid energy carrier substances, on one side, and on-site or on-board electrification by fuel cells, on the other.

Phosphoric acid fuel cells

PAFCs are a type of fuel cell that uses liquid phosphoric acid as an electrolyte. They were the first fuel cells to be commercialized. Developed in the mid-1960s and field tested since the 1970s, they have improved significantly with regard to stability, performance and cost. Such characteristics made the PAFC a good candidate for early stationary applications. In transport they are less often used, due to the danger from corrosive acid.

Alkali membrane fuel cells

Alkaline fuel cells (AFCs), also called alkaline membrane fuel cells (AMFCs) or alkaline anion exchange membrane fuel cells (AAEMFCs), are based on the transport of alkaline anions – usually hydroxide (OH–) – between electrodes. Originally, AFCs used aqueous potassium hydroxide (KOH) as an electrolyte. NASA used AFCs in the 1960s for the Apollo and Space Shuttle projects. Many recent developments have focused on the anion exchange membrane (AEM) – a critical aspect of AFCs – since it is responsible for the transport of OH– ions. This contrasts with PEM, which is an H+ conductive membrane, and is the main reason for there being less interest in this kind of fuel cell.

Molten carbonate fuel cells

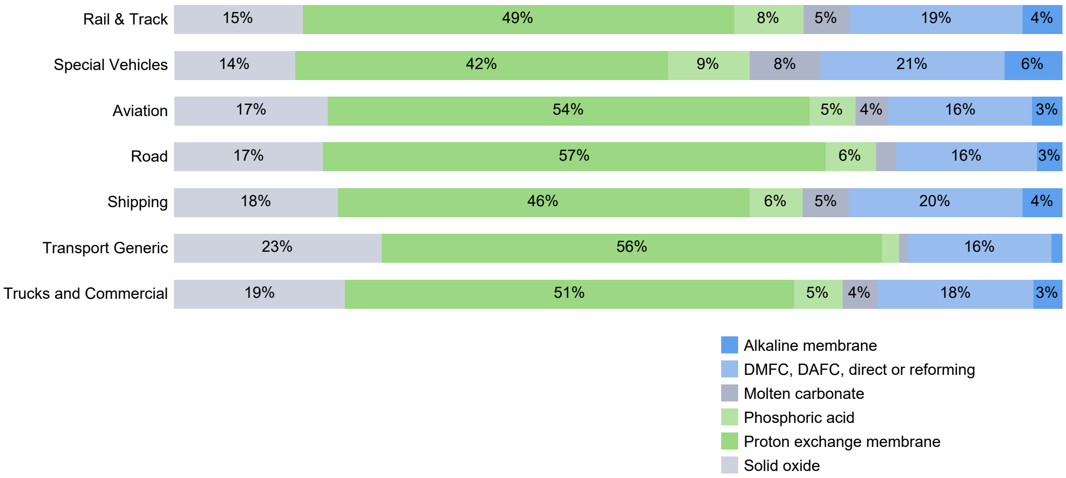
MCFCs work at temperatures above 600°C and aim at the direct conversion of natural gas or biogas. The high temperatures required makes the lower use of rare metals as catalysts possible and offer significant cost reductions over PAFCs. Unlike PAFCs, AFCs and PEMFCs, MCFCs do not require an external reformer in order to convert more energy-dense fuels into hydrogen. Because of the high temperatures at which MCFCs operate, these fuels are converted into hydrogen within the fuel cell itself through a process called internal reforming, which reduces cost (Leo, 2007). MCFCs are still rather huge in size and more research is required on the materials employed before they can be used for transport. They do have great potential, however, due to their durability. Currently, MCFCs are discussed mostly with regard to stationary use.

Patent landscape of fuel cell technologies

When analyzing the patent landscape for fuel cells in transportation, it is apparent that PEMFCs are playing the major role, followed by SOFCs and reformer-related technologies. PAFCs, AMFCs and MCFCs are currently less investigated and expected to be used primarily in stationary applications. MCFCs, PAFCs and SOFCs are all fairly durable and cheaper, but either run at high temperatures or employ corrosive acids. They most often have stationary applications, due their huge size and bulky industrial power production.

Technology breakdown by application field

Figure 13. **Distribution of patent filings related to various fuel cells types across different areas of transportation.**
Filing analysis of active and inactive patents, including utility models, all patents for fuel cells in transport. The dominance of PEMFCs (green) is visible over time. SOFCs (light grey) are typically in second place, with reformer/DMFCs/DAFCs (light blue close behind). All other fuel cell designs are not contributing comparable numbers.



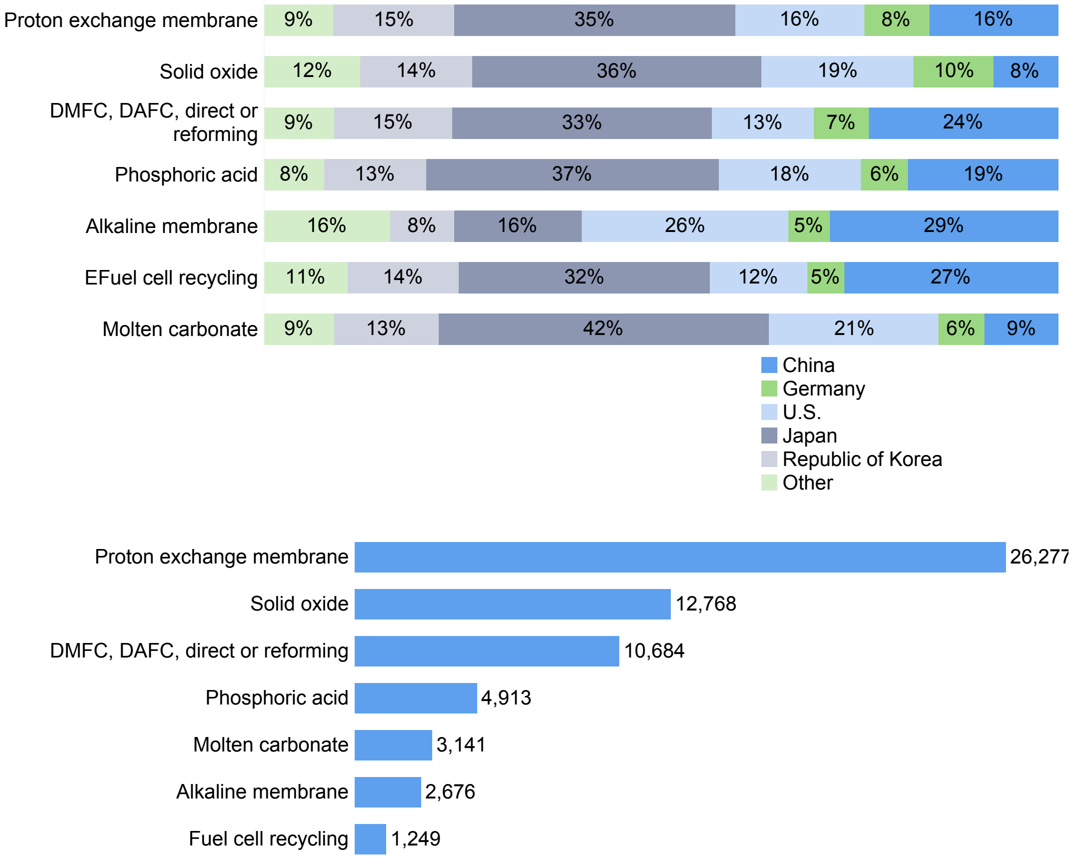
Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: DMFC is direct methanol fuel cell; DAFC is direct ammonia fuel cell.

In all transport applications, PEMFCs were found to be the most commonly used fuel cell type, with a share above 50 percent in nearly every application lfield. In shipping, trucks, and rail and track is there a slightly higher share of SOFCs, amounting to close to 20 percent. The highest share for reformers/crackers is in special vehicles (21 percent), followed by shipping (20 percent) and rail (20 percent). This suggests a greater acceptance of alternative fuels, such as methanol or ammonia, in these generally more industrial sectors. Both solvents are already common in industrial environments, such as harbors. Shipping and rail are also comparable to stationary setups, with generally larger installations and typically requiring greater reliability and longer durability.

Filing breakdown by origin of inventor

Figure 14. **Patent filings by technology and inventor origin. Top: contribution of different inventor origins to different fuel cell technology patenting activity. Bottom: number of filings by fuel cell technology.**

Inventors based in Japan have the highest contribution to all technologies, with the highest participation in the areas of PEMFC and SOFC. It is worth noting that China-based inventors have the highest contribution to filings related to alkaline membrane and fuel cell recycling.



Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: DMFC is direct methanol fuel cell; DAFC is direct ammonia fuel cell.

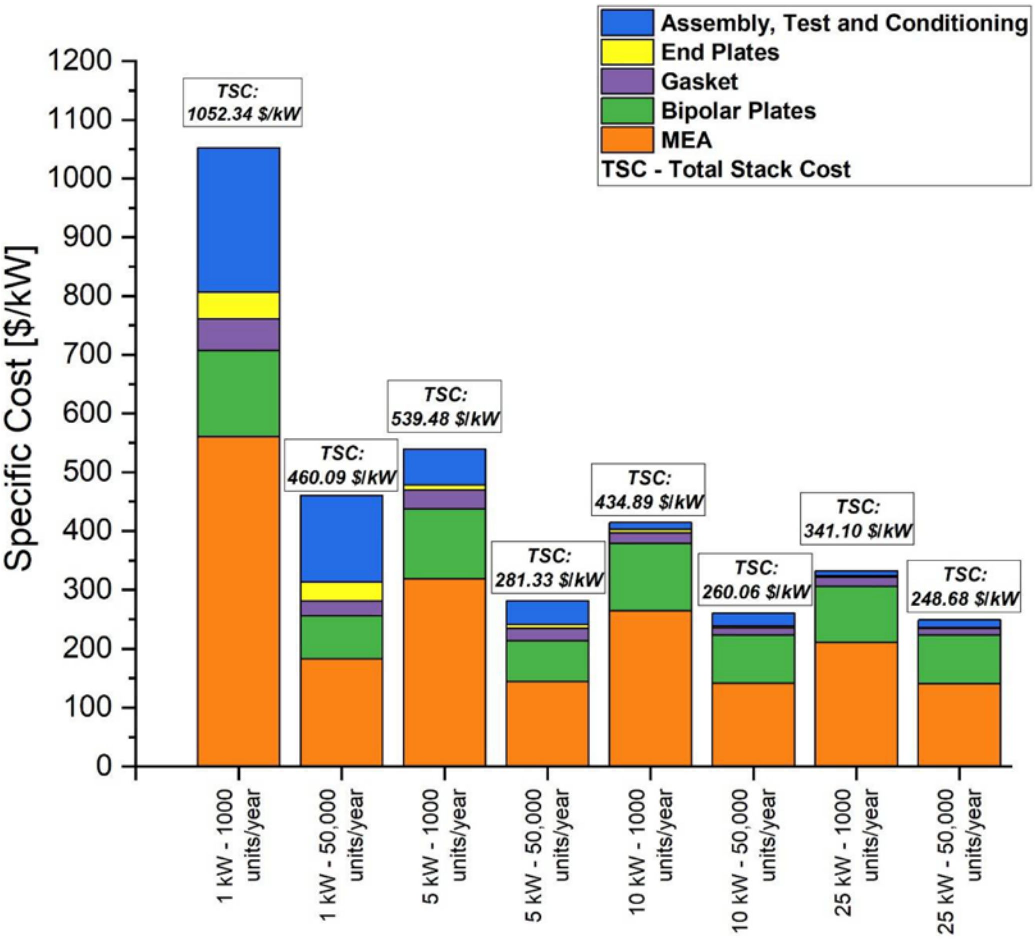
When analyzing the origin of fuel cell technologies in transport, it is evident that there are different areas of specialization or preference according to inventor profile. In PEMFCs and SOFCs, inventors based in Japan lead, followed by those from the U.S., China, the Republic of Korea and Germany. The landscape changes for reformer technology, PAFC and AMFCs, where inventors in China are in second position, also for MCFCs, with inventors in the Republic of Korea and U.S. leading. It is worth noting that Japan leads in fuel cell recycling, with China close behind, for the reasons discussed in the next chapter.

Fuel cell recycling

PEM fuel cells most often contain **rare platinum** catalysts among possible others. The bipolar plates are either made of steel or a comparable metal or coated carbon plates. The membranes are polymers such as polybenzimidazole (PBI) or per-fluorinated copolymers (for example the ones by Dupont under the tradename NAFION). Other fuel cell types contain further metals, ceramics and other potentially costly parts. The high price of fuel cells is, in comparison to batteries, only partly attribtable to the raw materials used; rather, the price of today's fuel cells is often largely determined by the production costs of the stacks. However, this is only true for current small volume production. The automated production scale-up expected in the next few years is likely to bring costs down and the price of materials then dominate. Projected stack prices of around USD 250/kW are wholly realistic and reported as offerings by Chinese market players in 2021 (source: interview with Jun Ma, CEO Simply Hydrogen, Shanghai). When it comes to recycling, however, it would seem that, whereas MEA (membrane electrode assembly, comprising the electrodes and membranes in a fuel cell stack) polymer membrane and bipolar plates are the biggest cost drivers, and generally only a few different parts are used, the largest single factor is the expensive platinum content (German Energy Solutions Initiative, 2020).

Figure 15. Cost breakdown of fuel cells for stationary applications in relation to production volume (estimated).

Membranes and bipolar plates seem to be the highest cost drivers.



Source: Cigolotti *et al*. (2021).

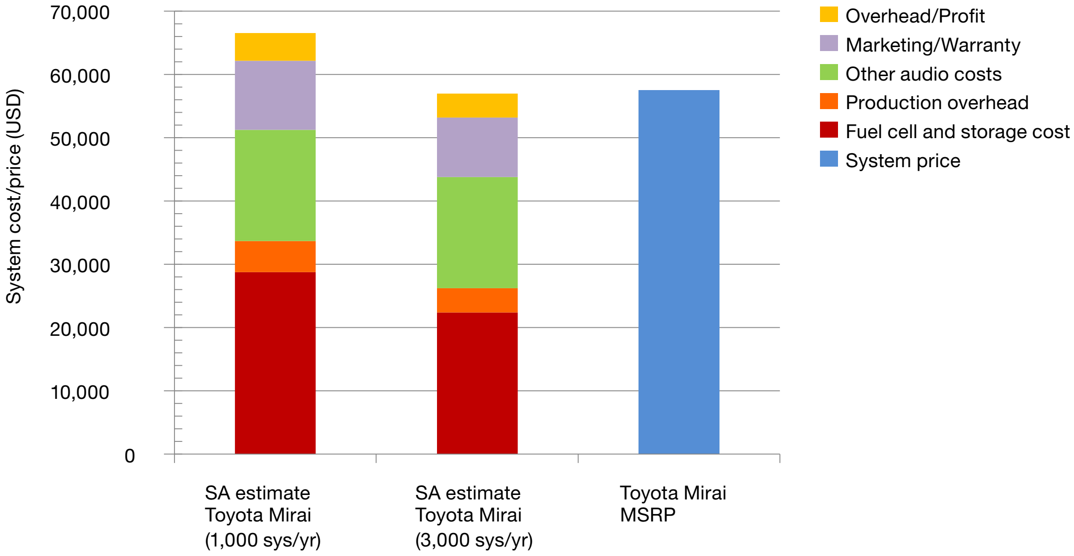
The cost breakdown in Figure 15 shows the two biggest cost drivers to be membranes and bipolar plates. As is often the case, only at smaller volumes does assembly represent a larger share of production costs. Automated production will be key to dramatically reducing costs, based on an interview carried out with Ruhlamat.com.

Cost analysis fuel cells in transport

In the transport field, it would seem that a stack price below USD 250/kW is realistic for market entry. The projected cost of fuel cells is under USD 50/kW for volumes above 500,000 units a year.

A typical domestic car demands about 50–100 kW of power from a typical 80 kW stack, costing around USD 20,000 for fuel cells, plus an additional USD 5,000–7,000 for storage tank, fuel and supply. In 2016, Toyota calculated the costs for the 2017 Mirai to be USD 184/kW, with a retail price of around USD 57,000.

Figure 16. Cost model for the Toyota Mirai fuel cell vehicle.
The strategic analysis estimate at 3,000 systems/year corresponds to Mirai's manufacturer's suggested retail price.



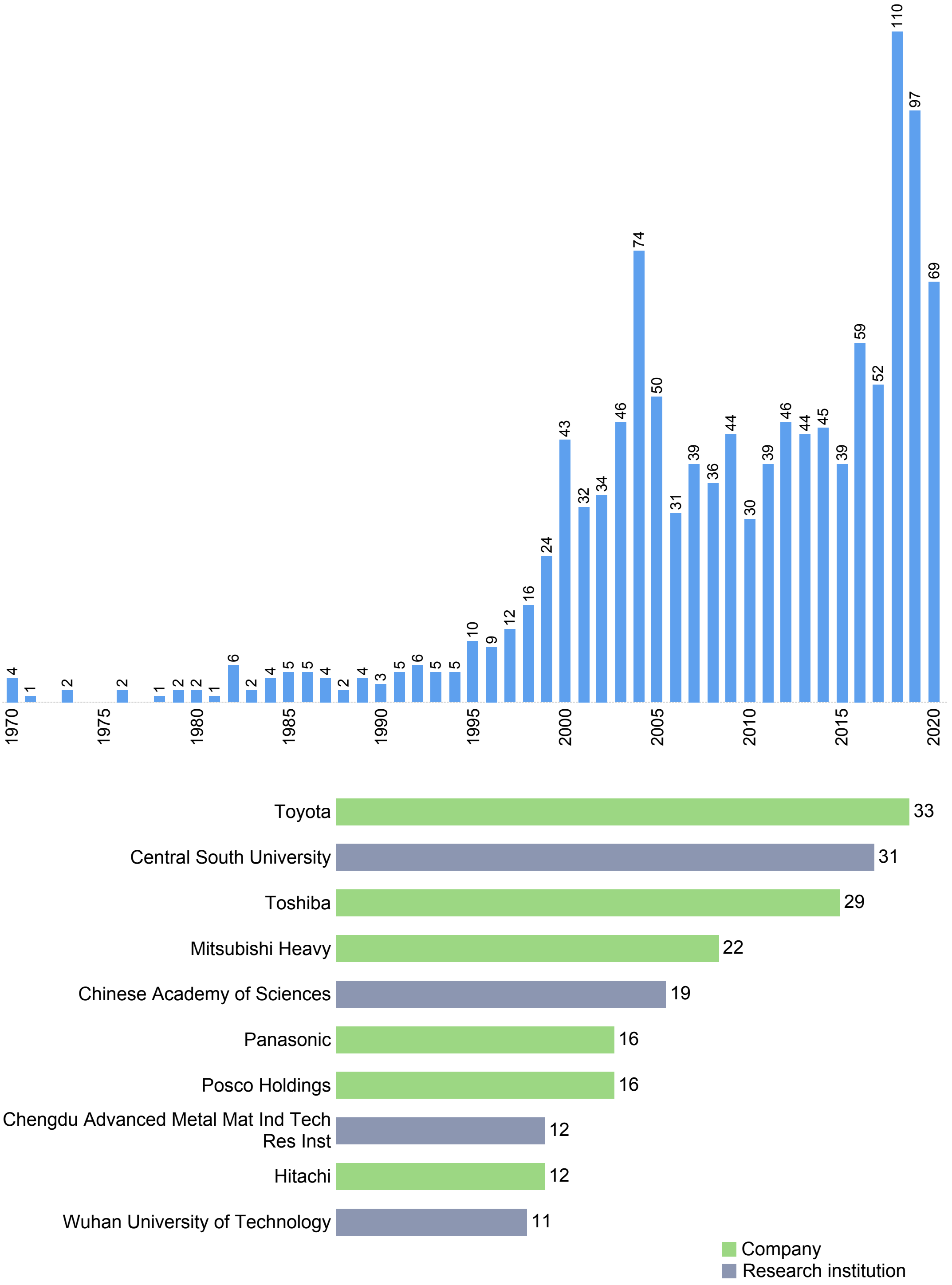
Source: James *et al*. (2017, 2021).
Note: DFMA® is Design for Manufacture and Assembly Analysis. SA is Strategic Analysis, the company that undertook the analysis. Produced by the company Strategic Analysis which applied the DFMA® (Design for Manufacture and Assembly Analysis) cost model for the purpose.

Fuel cell recycling roadmap

Analysis of the fuel cell recycling patent landscape shows overall activity to be small, but growing strongly, having nearly doubled in the last few years. This is consistent with a landscape where fuel cells are not yet being produced in vast numbers and only those few valuable parts of a fuel cell, namely the platinum-containing electrodes, extracted in any significant quantity through standard recycling processes, such as by pyrometallurgy. This will most probably change quickly with increasing scale-up. The goal will be to move from extracting only platinum (and producing too many toxic waste gases) to fully recycling all parts of a fuel cell. These aspects are currently under investigation and it is likely that the results of research will find their way into the design of future fuel cells. Concerning lithium batteries from EVs, a similar increase in interest in the topic can be expected. In batteries, we see more and more full-scale and automated recycling lines being built worldwide (Kumagi, 2021). However, when currently no more than 5 percent of lithium batteries are recycled (Woollacott, 2021), it is likely to take several years before this rate becomes reasonable – and the present fuel cell recycling rate falls far behind that of batteries!

Figure 17. **Fuel cell recycling patent filings by year of filing (1970–2020) and top 10 applicants in the field of fuel cell recycling.**

Patents discussing recycling remain few overall, but have visibly increased, especially in the last few years. The main players are a mix of universities (mostly in China) and companies (most in Japan).

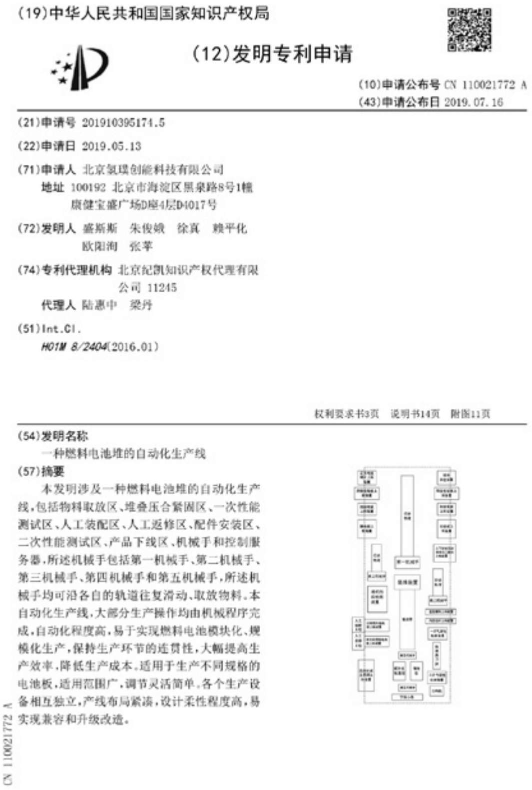


Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: There is an average 18-month delay between patent filing and publication. 2019 is the last year for which complete data are available.

Fuel cell automated production

The scaling-up of fuel cell production is only realistically possible, if it is automated and continuous. This is a relatively new, very dynamic field, with various facets remaining to be explored. Fuel cell stack production using robotics and other means has been visible in patents for several years, but now fully automated fuel cell manufacturing is beginning to be claimed in patent filings. The field is still small, but notice should be taken of the patent documents referring to this area, since more can be expected. The application of modern machine vision, image analysis, robotics and AI in automated production will make more of an impact in every area of production, but specifically in fuel cells. Stacking up to 800 layers in a fuel cell stack, with a high degree of precision in a fully hydrogen-sealed setup, is no easy task and not possible with standard machine setups. Interviews with small and medium enterprise(SME) machine players, such as German producer Ruhlamat in Suzhou, confirm the difficulties in machine construction and also the increasing demand from industry players for automated production lines (Fowler *et al.*, 2019; Ruhlamat, 2021; BMW, 2020).

Figure 18.1 **Example: Beijing Nowogen Tech, CN110021772.A. Automatic production line for a fuel cell stack.**



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(71)申请人 北京氢璞创能科技有限公司
地址 100192 北京市海淀区黑泉路8号1幢
康健宝盛广场D座4层D4017号

(72)发明人 盛斯斯　朱俊娥　徐真　赖平化
欧阳洵　张苹

(74)专利代理机构 北京纪凯知识产权代理有限
公司 11245
代理人 陆惠中　梁丹

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(54)发明名称
一种燃料电池堆的自动化生产线

(57)摘要
本发明涉及一种燃料电池堆的自动化生产线，包括物料取放区、堆叠压合紧固区、一次性能测试区、人工装配区、人工返修区、配件安装区、二次性能测试区、产品下线区、机械手和控制服务器，所述机械手包括第一机械手、第二机械手、第三机械手、第四机械手和第五机械手，所述机械手均可沿各自的轨道往复滑动、取放物料。本自动化生产线，大部分生产操作均由机械程序完成，自动化程度高，易于实现燃料电池模块化、规模化生产，保持生产环节的连贯性，大幅提高生产效率，降低生产成本。适用于生产不同规格的电池板，适用范围广，调节灵活简单。各个生产设备相互独立，产线布局紧凑，设计柔性程度高，易实现兼容和升级改造。

CN 110021772 A

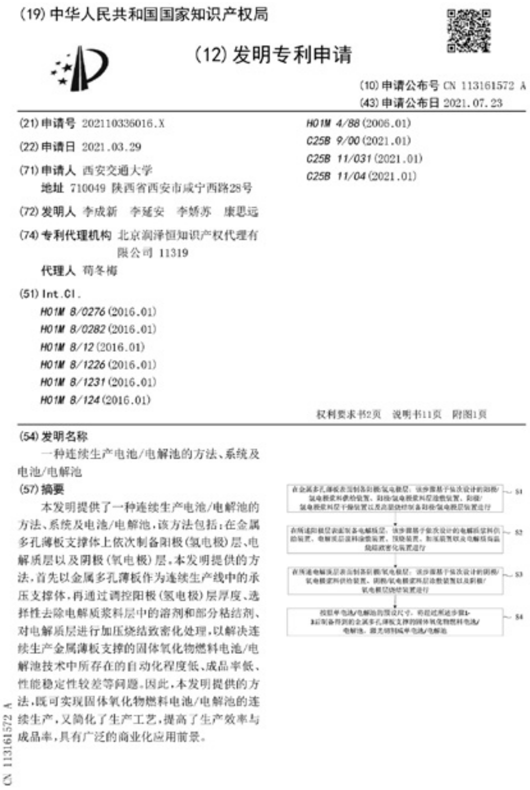
Applicants　BEIJING NOWOGEN TECH CO LTD +
Inventors　SHENG SISI; ZHU JUN'E; XU ZHEN; LAI PINGHUA; OUYANG XUN; ZHANG PING +

Automatic production line of fuel cell stack

Abstract

The invention relates to an automatic production line of a fuel cell stack. The automatic production line comprises a material taking and placing region, a stack lamination fastening region, a primaryperformance test region, an artificial assembly region, an artificial rework region, a part installation region, a secondary performance test region, a product off-line region, a manipulator and a control server, wherein the manipulator comprises a first manipulator, a second manipulator, a third manipulator, a fourth manipulator and a fifth manipulator, and the manipulators can slide along respective rails in a reciprocating way to take and place materials. In the automatic production line, a large part of production operation is completed by a mechanical program, high automation is achieved, modular and large-scale production of a fuel cell is easy to achieve, the continuity of production links is maintained, the production efficiency is substantially improved, the production cost is reduced, the automatic production line is suitable for producing different specifications of cell panels, is wide in application range and is flexible and simple to adjust, each production equipment isindependent, the production line is compact in layout, high in design flexibility, and compatibility, upgrading and transformation are easily achieved.

Figure 18.2 Example: University Xi An Jiatong, CN113161572.A. Method and system for continuously producing fuel cells/electrolytic cells and battery/electrolytic cells.



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(71) 申请人 西安交通大学
地址 710049 陕西省西安市咸宁西路28号
(72) 发明人 李成新　李延安　李娇苏　康思远
(74) 专利代理机构 北京润泽恒知识产权代理有限公司 11319
代理人 荀冬梅
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(54) 发明名称

一种连续生产电池/电解池的方法、系统及电池/电解池

(57) 摘要

本发明提供了一种连续生产电池/电解池的方法、系统及电池/电解池，该方法包括：在金属多孔薄板支撑体上依次制备阳极（氢电极）层、电解质层以及阴极（氧电极）层。本发明提供的方法，首先以金属多孔薄板作为连续生产线中的承压支撑体，再通过调控阳极（氢电极）层厚度、选择性去除电解质浆料层中的溶剂和部分粘结剂、对电解质层进行加压烧结致密化处理，以解决连续生产金属薄板支撑的固体氧化物燃料电池/电解池技术中所存在的自动化程度低、成品率低、性能稳定性较差等问题。因此，本发明提供的方法，既可实现固体氧化物燃料电池/电解池的连续生产，又简化了生产工艺，提高了生产效率与成品率，具有广泛的商业化应用前景。

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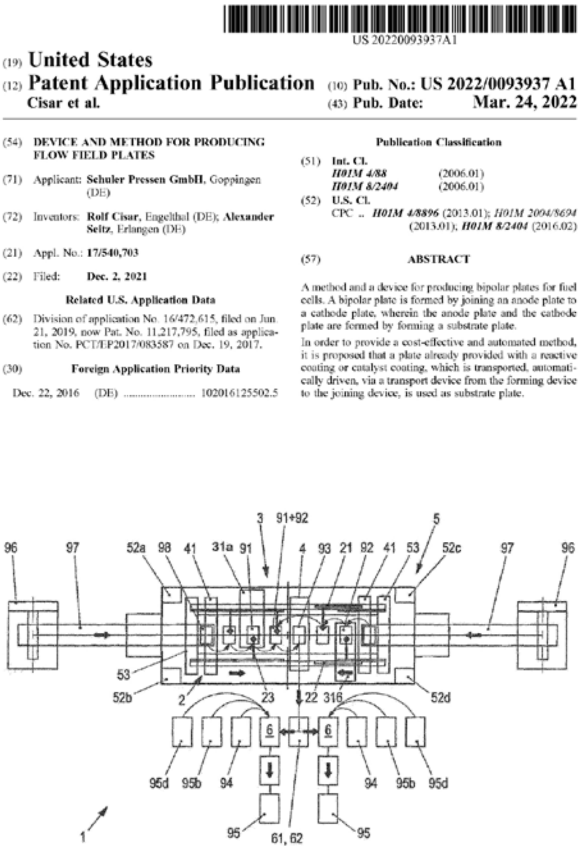
Applicants	UNIV XI AN JIAOTONG – 西安交通大学; XI'AN JIAOTONG UNIVERSITY
Inventors	LI CHENGXIN; LI YAN'AN; LI JIAOSU; KANG SIYUAN – 李成新; 李延安; 李娇苏; 康思远; LI CHENGXIN; LI YAN'AN; LI JIAOSU; KANG SIYUAN

Method and system for continuously producing cell/electrolytic cell and battery/electrolytic cell

Abstract

The invention provides a method and system for continuously producing a cell/electrolytic cell and the cell/electrolytic cell. The method comprises the step of sequentially preparing an anode (hydrogen electrode) layer, an electrolyte layer and a cathode (oxygen electrode) layer on a metal porous thin plate supporting body. The method provided by the invention comprises the steps of firstly, taking a metal porous thin plate as a pressure-bearing supporting body in a continuous production line, then regulating and controlling the thickness of an anode (hydrogen electrode) layer, selectively removing a solvent and part of a binder in an electrolyte slurry layer, and carrying out pressure sintering densification treatment on an electrolyte layer, thereby solving problems that the automation degree is low, the yield is low, and the performance stability is poor in the technology of continuously producing the solid oxide fuel cell/electrolytic cell supported by the metal sheet. Therefore, according to the method provided by the invention, the continuous production of the solid oxide fuel cell/electrolytic tank can be realized, the production process is simplified, the production efficiency and the yield are improved, and the method has a wide commercial application prospect.

Figure 18.3 Example: Andritz, US 2022/0093937 A1. Device and method for producing flow field plates.



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(54) **DEVICE AND METHOD FOR PRODUCING FLOW FIELD PLATES**

(71) Applicant: **Schuler Pressen GmbH**, Goppingen (DE)

(72) Inventors: **Rolf Cisar**, Engelthal (DE); **Alexander Seitz**, Erlangen (DE)

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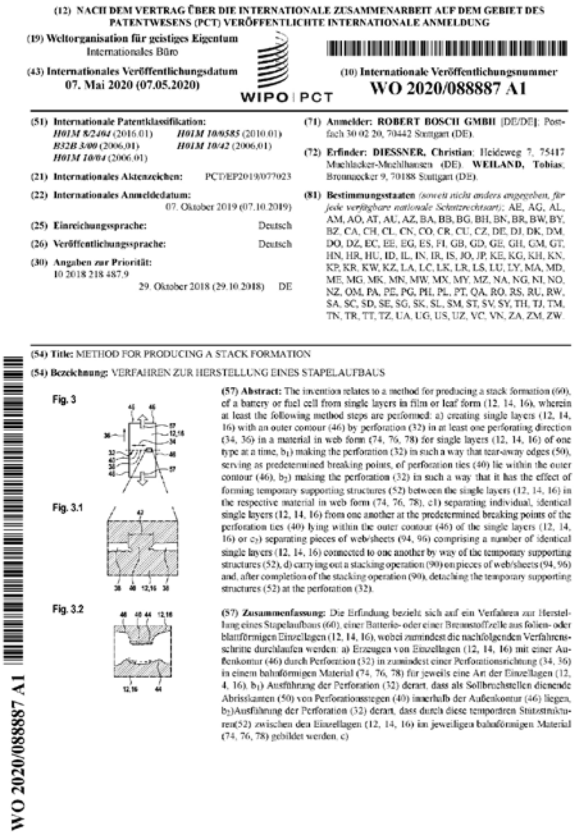
(57) **ABSTRACT**

A method and a device for producing bipolar plates for fuel cells. A bipolar plate is formed by joining an anode plate to a cathode plate, wherein the anode plate and the cathode plate are formed by forming a substrate plate.

In order to provide a cost-effective and automated method, it is proposed that a plate already provided with a reactive coating or catalyst coating, which is transported, automatically driven, via a transport device from the forming device to the joining device, is used as substrate plate.

Figure 18.4 Example: BOSCH, WO202008887. Method for producing a fuel cell stack.



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(71) **Anmelder: ROBERT BOSCH GMBH** [DE/DE]; Postfach 30 02 20, 70442 Stuttgart (DE).

(72) **Erfinder: DIESSNER, Christian**; Heideweg 7, 75417 Muehlacker-Muehlhausen (DE). **WEILAND, Tobias**; Bronnaecker 9, 70188 Stuttgart (DE).

(81) **Bestimmungsstaaten** *(soweit nicht anders angegeben, für jede verfügbare nationale Schutzrechtsart)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(54) **Title:** METHOD FOR PRODUCING A STACK FORMATION

(54) **Bezeichnung:** VERFAHREN ZUR HERSTELLUNG EINES STAPELAUFBAUS

Fig. 3

Fig. 3.1

Fig. 3.2

(57) **Abstract:** The invention relates to a method for producing a stack formation (60), of a battery or fuel cell from single layers in film or leaf form (12, 14, 16), wherein at least the following method steps are performed: a) creating single layers (12, 14, 16) with an outer contour (46) by perforation (32) in at least one perforating direction (34, 36) in a material in web form (74, 76, 78) for single layers (12, 14, 16) of one type at a time, b_1) making the perforation (32) in such a way that tear-away edges (50), serving as predetermined breaking points, of perforation ties (40) lie within the outer contour (46), b_2) making the perforation (32) in such a way that it has the effect of forming temporary supporting structures (52) between the single layers (12, 14, 16) in the respective material in web form (74, 76, 78), c1) separating individual, identical single layers (12, 14, 16) from one another at the predetermined breaking points of the perforation ties (40) lying within the outer contour (46) of the single layers (12, 14, 16) or c_2) separating pieces of web/sheets (94, 96) comprising a number of identical single layers (12, 14, 16) connected to one another by way of the temporary supporting structures (52), d) carrying out a stacking operation (90) on pieces of web/sheets (94, 96) and, after completion of the stacking operation (90), detaching the temporary supporting structures (52) at the perforation (32).

(57) **Zusammenfassung:** Die Erfindung bezieht sich auf ein Verfahren zur Herstellung eines Stapelaufbaus (60), einer Batterie- oder einer Brennstoffzelle aus folien- oder blattförmigen Einzellagen (12, 14, 16), wobei zumindest die nachfolgenden Verfahrensschritte durchlaufen werden: a) Erzeugen von Einzellagen (12, 14, 16) mit einer Außenkontur (46) durch Perforation (32) in zumindest einer Perforationsrichtung (34, 36) in einem bahnförmigen Material (74, 76, 78) für jeweils eine Art der Einzellagen (12, 4, 16), b_1) Ausführung der Perforation (32) derart, dass als Sollbruchstellen dienende Abrisskanten (50) von Perforationsstegen (40) innerhalb der Außenkontur (46) liegen, b_2)Ausführung der Perforation (32) derart, dass durch diese temporären Stützstrukturen(52) zwischen den Einzellagen (12, 14, 16) im jeweiligen bahnförmigen Material (74, 76, 78) gebildet werden, c)

WO 2020/088887 A1

Fuel cell technologies in transportation

That transportation is at present responsible for close to one-quarter (24 percent) of the CO_2 emitted directly from fuel combustion globally highlights the huge advancements to be made in reaching climate change goals through the electrification of modern transport. However, this will only be the case if the electricity required is generated from non-emissive sources. Highly efficient, electrically-driven vehicles have been produced for many years. The problem that remains is the on-site or in-car availability of electrical energy. It has always been more convenient and simpler to burn materials with a high energy density, namely liquid fuels such as gasoline.

The electrification of transport challenge can be solved by batteries (storing electrical power generated off-site) or by electrical power generators, which realistically are likely to be fuel cells. Batteries are typically heavy and unable to store the equivalent amount of energy by weight as fuels. Fuel cells can produce electrical power on board a vehicle, be it a car, bus, ship or airship, without "burning" emissive fuels but instead hydrogen or hydrogen precursors. In most credible scenarios, the energy produced by fuel cells will continue to be stored in on-site batteries in order to supply concentrated power on demand. Combining batteries with on-site electrical power generation greatly extends a vehicles' range, allowing batteries to be smaller and increasing significantly the flexibility available for the electrification of transport.

In the previous chapter we saw the extent to which this technology has been investigated and developed since it first originated. Leaving discussions about the hydrogen generation, its availability and the related infrastructure to other studies, this chapter focuses on the **transportation sector** itself and the electrification of transport vehicles using fuel cells to convert hydrogen into electrical energy on-site. To this end, only those patents that combine the features of fuel cells with transportation-related application aspects are analyzed in regard to developments within the last 20 years.

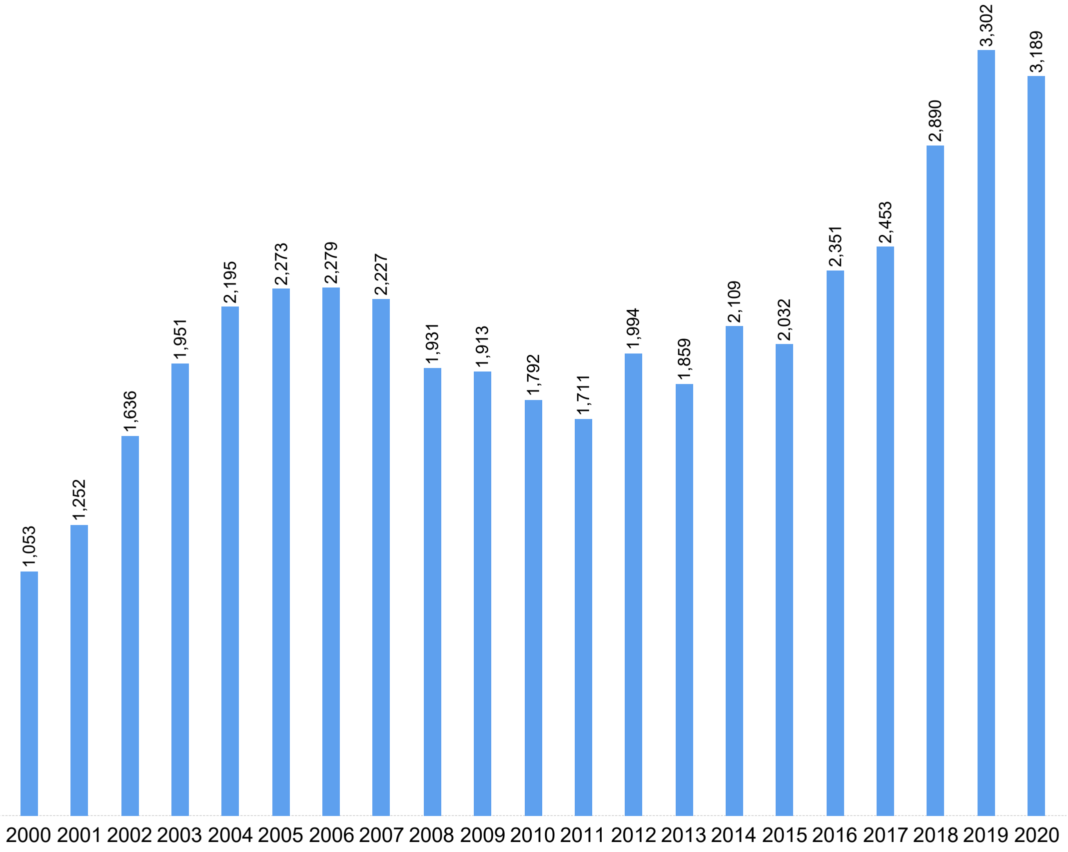
This section analyzes global developments, as well as those across individual patent jurisdictions, using the patent applications filed each year from 2000 to 2019 as indicators. As data for the years 2020 and 2021 are incomplete due to publication delays (with an average 18-month delay from patent application to its publication), most of the illustrations stop at 2019, the last calendar year for which complete data exist. The cutoff date for the patent data retrieval in this analysis is March 24, 2022; the patent dataset includes patent documents published up to that date.

Figure 19 below shows global patent filings in fuel cell technologies have steadily increased over recent years, almost doubling in the last decade from 1,792 in 2010 to 3,302 in 2019. As discussed above, fuel cell patent development has fluctuated over time, mainly due to external factors such as changes in demand or research funding.

Global patent filing for patents describing fuel cells in transport, 2000–2020

Figure 19. **Number of patent families related to hydrogen fuel cell technologies in transport by year of first filing, from 2000 to 2020.**

Filings have been on an upward trend since 2015 and reached an all-time peak in 2019.



Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: There is an average 18-month delay between patent filing and publication. 2019 is the last year for which complete data are available.

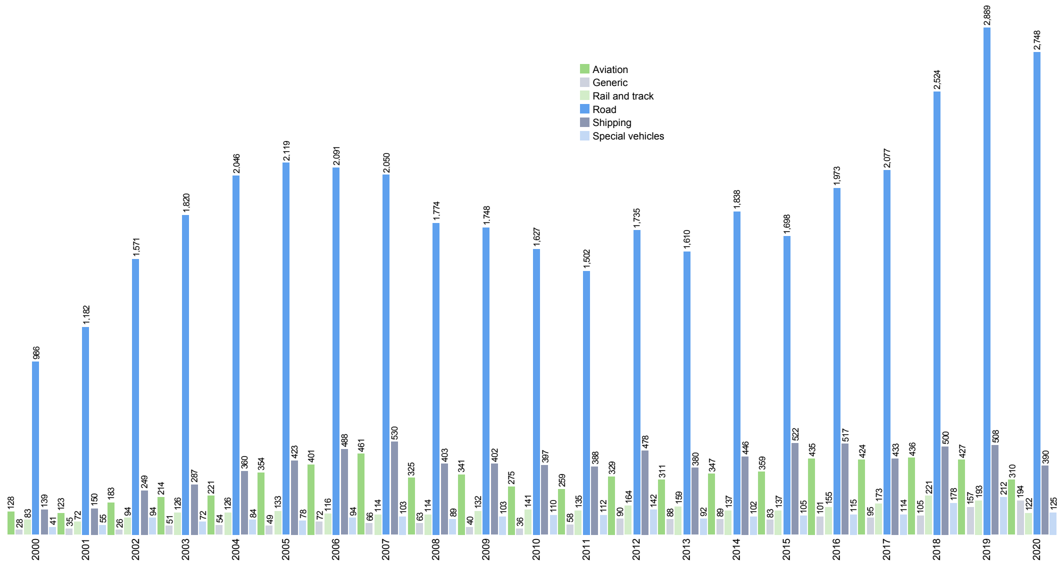
Market application breakdown

For the purposes of this report, total patents were divided into six application fields so as to better highlight trends. We analyzed road vehicles, including specific analyses of trucks and commercial or cargo road vehicles; rail and track-side vehicles; shipping and water-side transport; aircraft and other air-side vehicles, such as vertical take-off and landing (VTOL) craft ("flying cars") or drones (unmanned aerial vehicles, UAVs); and, finally, special vehicles. As a group, special vehicles are a collection of different typical commercial vehicles, including fork-lifts, airport tugs, tractors and dredgers, and various constructions vehicles. Finally, there remained a category of patent documents that did not describe any specific road or other transportation vehicle or area for application and therefore generic in terms of use (for instance, there was no wording other than simply "vehicles" in the patent document). Figure 20 shows the development of these six application fields over time. It is clear from this that road vehicles represent by far the largest field of application, leading developments and defining trends in transportation, followed by shipping and rail applications.

Global patent filing by field of transportation application, 2000–2020

Figure 20. **Number of patent families filed in transportation by application field, from 2000 to 2020. Filing year is a patent family's first filing year.**

Road-related applications (cars, motorcycles, trucks, and so on) dominate the field, accounting for a majority of patents in fuel cells in the transport data set.



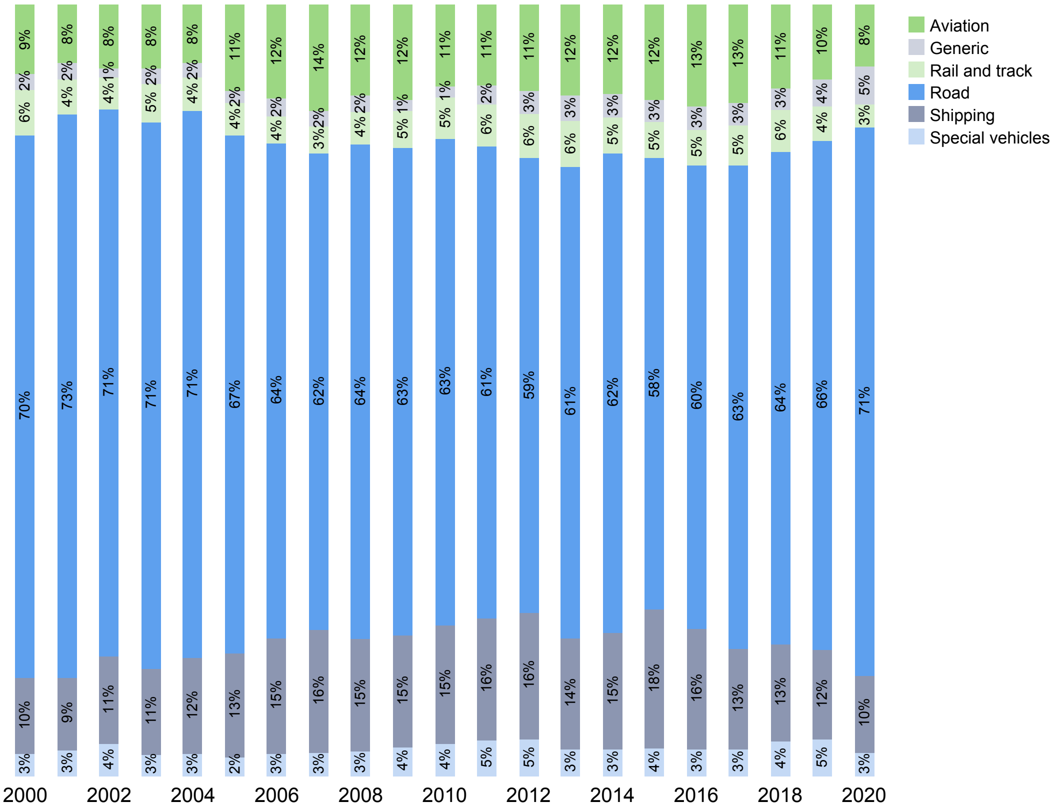
Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: There is an average 18-month delay between patent filing and publication. 2019 is the last year for which complete data are available.

Patent filings for shipping are in second place, followed by aviation and rail, but with significantly lower numbers. Filings in special vehicles have also been growing, especially in recent years, although filings are rather few in number. The order of market entrance is reversed, however. Special vehicles – namely, commercial vehicles, including fork-lifts, airport tugs, tractors and dredgers, and various constructions vehicles – may be a niche for fuel cells but are increasing at a steady pace. In general, the patent numbers reflect the overall development of fuel cells described in the General overview to the report.

The strength of the link between hydrogen fuel cells and road applications is confirmed in the analysis of share structure in Figure 21. This shows the share of patents describing road-related applications increased from an already substantial 58 percent in 2015 up to 71 percent during the last five years of the reporting period (this may change slightly as complete data for 2020 becomes available). In the same period, all other applications lost shares; however, such small changes between filing years should not be over-interpreted. In addition, it should be noted that a significant overlap of around 20 percent exists between applications, and must to be taken account of when analyzing this chart. Moreover, many patents describe several possible applications, whereas few claim only one specific application.

Global patent filings by field of application, 2000–2020

Figure 21. **Overall application filing over time, according to patent filings by year of first filing and by application field. Filing year is a patent family’s first year of filing.**
Special vehicles filings are few in number, reflecting a niche position in the transport market.



Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: There is an average 18-month delay between patent filing and publication. 2019 is the last year for which complete data are available.

Innovation origin view

In what follows, we analyze the origin of inventions using the inventor’s address as a proxy for the origin of the innovation. The grouping of patent filings by inventor’s origin shows more than half attributable to China-based inventors (42 percent of filings in 2019 are attributable to China alone), with Japan in second place accounting for around 22 percent in 2019, followed by Germany with 14 percent. Overall, the top five inventor origins, namely, China, Japan, Germany, the Republic of Korea and the U.S., are the source of around 94 percent of total filings, and the top 10 for just under 98 percent. This shows inventors from this small group of jurisdictions account for almost of the entire patenting activity.

Table 1 shows the key indicators for the 20 most important filing jurisdictions. For each jurisdiction, the filing trend is shown as a chart from 2000 to 2019. It is important to note that scaling varies between the bar graphs. This is deliberate, so as to focus on trend development in the respective jurisdictions as essential information. Absolute filing activities are shown in addition for five points in time to enable a comparison of levels and dynamics. Furthermore, filings for the individual application areas as of 2019 are shown to better appreciate the filings structure.

Table 1 supports the view that China is responsible for the bulk of current filings. In addition, it is apparent from the time trend that China has only developed this dynamic in recent years. Indeed, just a decade ago, China ranked down in fifth place in terms of annual filings.

Furthermore, it is evident that, apart from China, Germany alone exhibits a significant growth dynamic. Germany has been able to grow its filings by around 50 percent compared with 2015. Japan meanwhile has stagnated at a comparatively high level during the last decade, having reduced its filings by around two-thirds since 2005. The U.S. is showing a downward trend similar to Japan, albeit at a lower level, its filings having almost halved filings since 2005.

A particularly noteworthy development is to be observed with regard to inventors based in the Republic of Korea. Although inventors in the Republic of Korea made more than twice as many filings in 2010 than in 2005, and these increased further up until 2015, they have since declined in recent years. Furthermore, the Republic of Korea expanded its filing activities at a time when filings were already declining in Japan and the US. Moreover, the Republic of Korea inventors built momentum significantly earlier than in China. We can therefore observe a development trend opposite to that seen in Japan and the U.S., as well as a clear time lead over China plus a declining dynamic in recent years. Thus, while China and Germany are increasing patent filings at the present time, other countries are consolidating at a low level.

The story for countries more broadly is less clear-cut due to significantly lower filings; accordingly, a country trend cannot be derived in either one direction or the other.

Table 1. **Top 20 inventor origins, with filing trends over time and across transportation application fields.**

Active patent portfolios of the leading 20 countries by origin of the inventor in fuel cells in transportation (left part of table) compared to recent patent filing activity (all patents, active and inactive, right part of table). Although Japan leads in total filings over the years, filings from China are rapidly rising.

Jurisdiction	Active patent portfolios	Cum. filings 00-19	Filings 2000	Filings 2005	Filings 2010	Filings 2015	Filings 2019	Road filings 2019	Rail filings 2019	Shipping filings 2019	Aviation filings 2019	Special filings 2019	Others filings 2019
Japan		16,331	565	1355	589	509	541	511	23	55	54	49	18
China		7,257	13	129	211	476	1,760	1,617	64	163	81	69	43
Republic of Korea		5,287	60	161	358	449	285	212	9	120	77	12	21
U.S.		5,022	158	359	255	194	175	152	29	59	80	35	5
Germany		4,457	152	174	223	242	386	277	48	69	83	28	61
France		939	37	49	42	41	48	29	7	14	26	7	3
Canada		697	30	30	29	41	22	19	3	6	3	1	0
U.K.		460	12	10	36	30	18	11	2	3	9	3	0
India		188	1	9	8	15	10	8	0	1	3	2	0
Russia		186	6	11	14	4	6	4	2	1	1	0	0
Italy		183	1	4	13	9	13	11	1	3	3	3	1
Switzerland		167	2	15	9	8	6	5	0	1	3	0	1
Austria		159	3	5	7	6	23	13	2	1	5	3	5
Netherlands		134	4	4	9	2	10	9	1	3	3	4	0
Sweden		105	2	5	4	0	6	5	0	1	1	0	1
Spain		104	0	3	11	7	8	7	3	3	4	3	0
Australia		102	5	7	8	6	2	2	0	1	0	0	0
Denmark		91	1	4	4	1	10	9	0	3	1	1	0
Israel		82	2	3	5	7	6	6	1	2	3	2	0
Belgium		67	0	1	1	5	6	5	2	2	5	1	0

The same top five inventor locations dominate in every transport application field, an exception being the Republic of Korea with regard shipping. It is noticeable that the Republic of Korea pays special attention to shipping applications (120 patent filings in 2019) and ranks second behind China, with 163 filings in 2019.

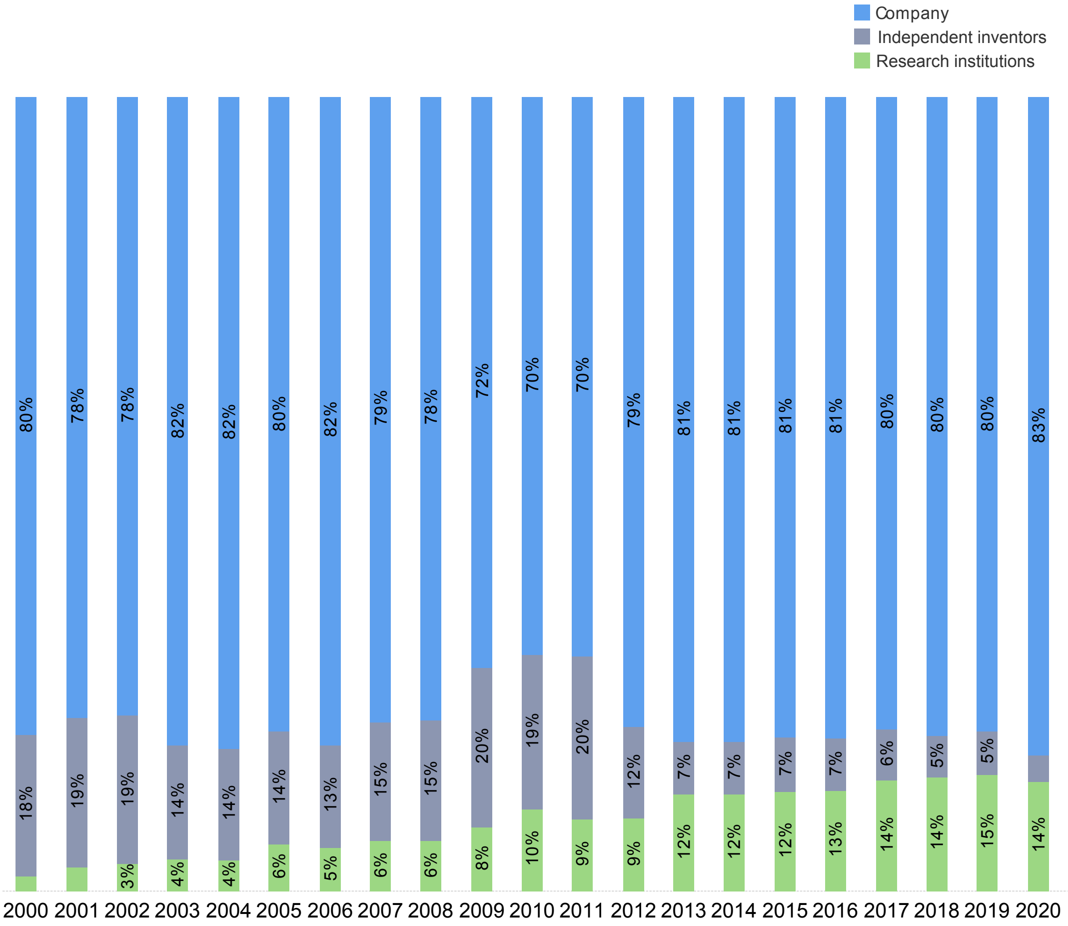
Patent filings by patent applicant type

A comparison of the patent applicant-type structure shows a majority of patents in this area are filed by companies. In 2000, the share of filings by companies was 80 percent (Figure 22). This has changed only slightly over time and reached 80 percent again in 2019. The share of filings by universities and research institutions increased from around 2 percent in 2000 to 15 percent in 2019.

Global patent filings by applicant type, 2000–2020

Figure 22. **Share of patent filings by applicant type, 2000–2020. Filing year is a patent family's first year of filing.**

Companies dominate patent filings in the last 20 years, with research institutions accounting for about 15% of the filings.

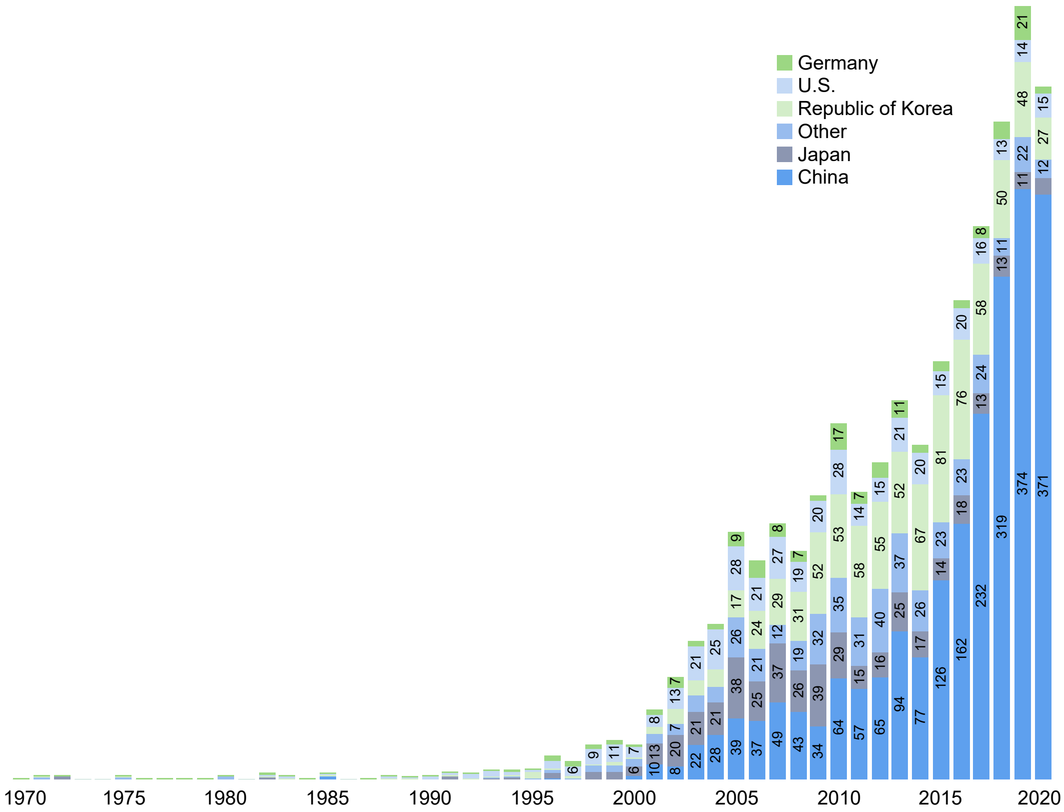


Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: There is an average 18-month delay between patent filing and publication. 2019 is the last year for which complete data are available.

Patent filings over time for universities and research institutions

Figure 23. **Global patent filings from universities and research institutions, 1970–2020. Filing year is a patent family's earliest filing year.**

Chinese universities and research institutions account for a major proportion of filings in the last five years, increasing in number from the years before.



Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: There is an average 18-month delay between patent filing and publication. 2019 is the last year for which complete data are available.

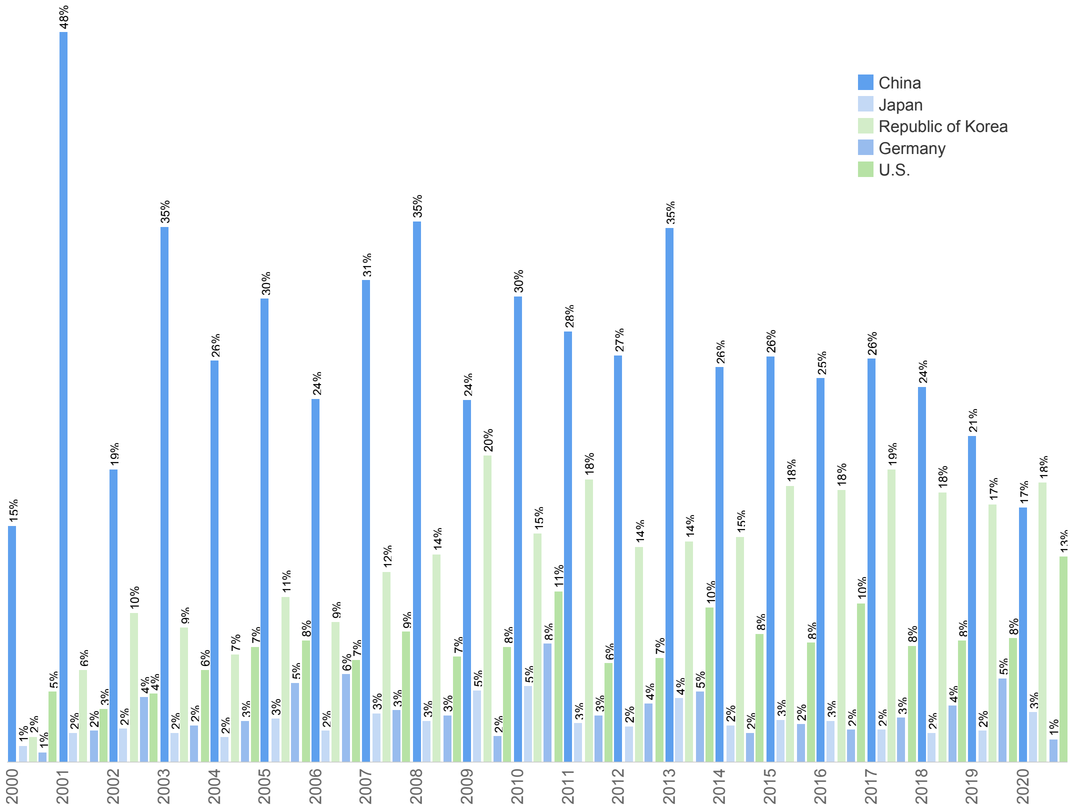
The increase seen in filings by research institutions illustrated in Figure 23 is driven by overlapping structural effects: a general decline in filing activity can be observed in many jurisdictions (with the notable exceptions of China, the Republic of Korea and Germany), while the special structure of China and the Republic of Korea may also play an important role.

Figure 24 shows the filings by research institution as a share of total filings for the top five jurisdictions. The share of research institutions in China's total filings can be seen to have fluctuated between about 20 and 35 percent in recent years, well above the current global share of 14 percent. Due to China's importance in absolute terms, the overall global share for research institutions is a growing one.

Share of patents filed by universities and public research institutions in the top five jurisdictions, 2000–2020

Figure 24. Shares of patent filings by universities and public research institutions in China, Japan, the Republic of Korea, Germany and the U.S., 2000–2020.

Shares for China and the Republic of Korea are significantly higher than those of other top jurisdictions. As China is the most active filer overall, the global share of research filings has grown.

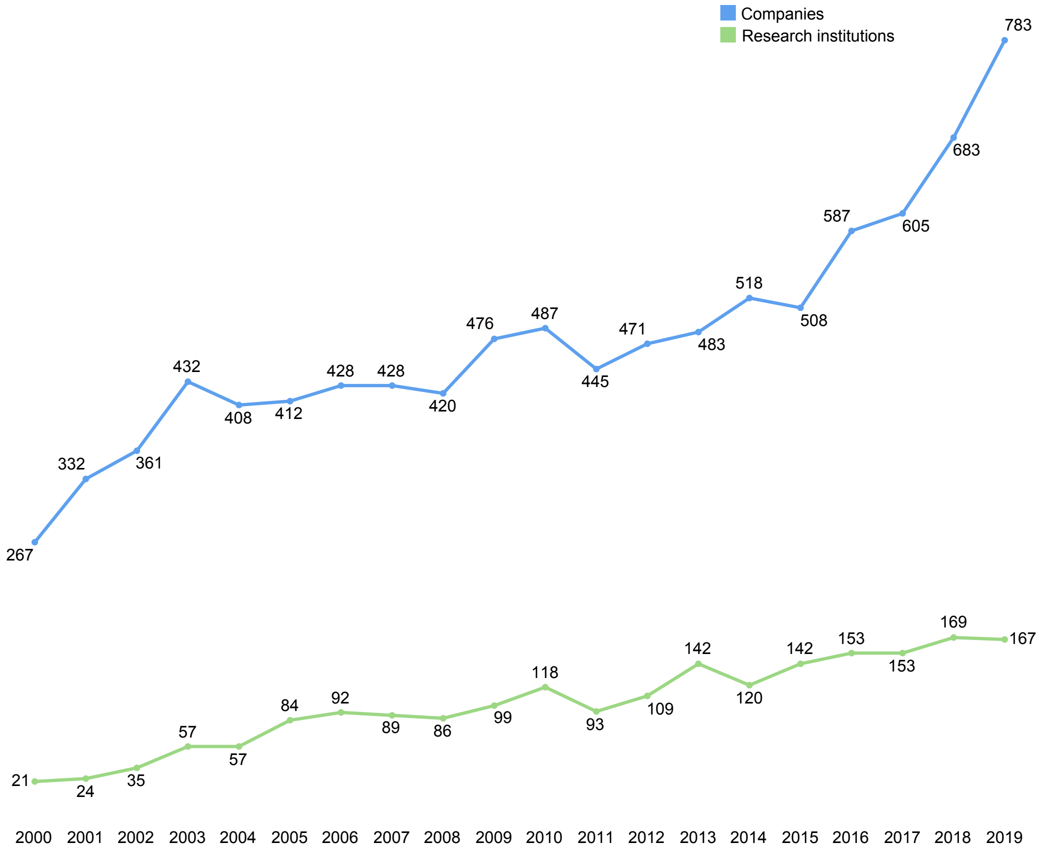


Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: There is an average 18-month delay between patent filing and publication. 2019 is the last year for which complete data are available.

Overall, the number of companies and research institutions active in this field is increasing significantly. Measuring the number of companies with at least one filing in any given year as a measure of companies steadily active in the field or ramping up a portfolio, the number of active companies has almost tripled over the last 20 years from 267 companies in 2000 to 783 companies in 2019 (Figure 25). Over the same period, the number of active research institutions increased eightfold to 167 compared to 2000 (21 active research institutions).

Number of companies and research institutions with at least one filing in any given year, 2000–2019

Figure 25. **Comparison between number of companies and universities and research institutions with at least one filing a year from 2000 to 2019.**
The number of companies filing at least one patent has almost doubled in the last 10 years, whereas the number of research institutions has increased only slightly.

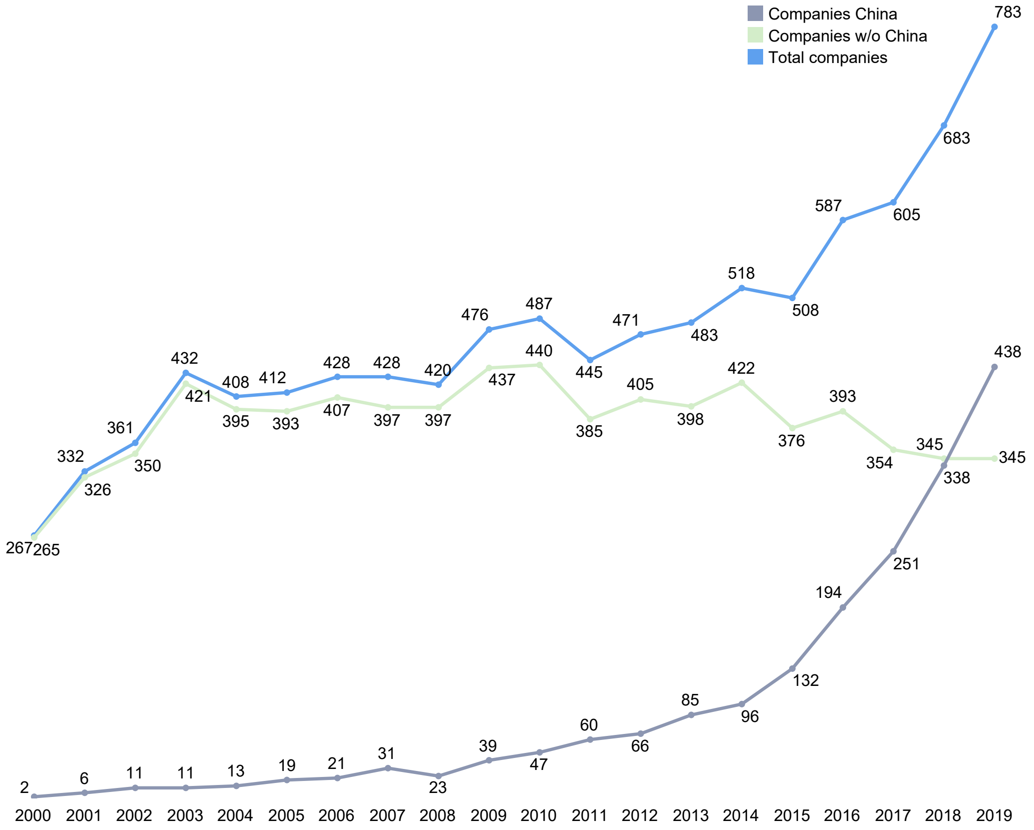


Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: There is an average 18-month delay between patent filing and publication. 2019 is the last year for which complete data are available. Only companies and universities are considered which file at least a patent document per year. Universities in general as well as companies not filing every year in fuel cells in transport are excluded.

The growing importance of China is also reflected in the number of China-based companies there are in this field. Out of a total of 783 companies active in the field in 2019, 438 were based in China (Figure 26). Due to project scope restrictions not allowing comprehensive information on the headquarters of companies to be collected, an approximation has been made by identifying companies in this technology field which have exclusively inventors with an address in China. In 2019, this was true for 56 percent of all companies active in this technology (438 out of a total of 783). Without the contribution from China, the number of active companies would have remained at a similar level for more than 15 years and have even dipped slightly during the last few years.

Number of companies with at least one filing in any given year, China and global development, 2000–2019

Figure 26. **Comparison between companies filing at least one patent application a year from 2000 to 2019 – overall results, results without Chinese companies, and Chinese companies alone.** *Companies from China have contributed significantly to the remarkable increase in patent filings since 2015. Without their presence filing would have remained at the same level or even decreased slightly.*



Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: There is an average 18-month delay between patent filing and publication. 2019 is the last year for which complete data are available. By selecting companies with at least one patent filing in each year the aim is to consider only those steadily active in the field and building up the size of a portfolio. As well as filtering out universities, those companies who ordinarily file in other areas and only mention fuel cells as an alternative or option, and therefore do not file a patent in the field every year, are also excluded.

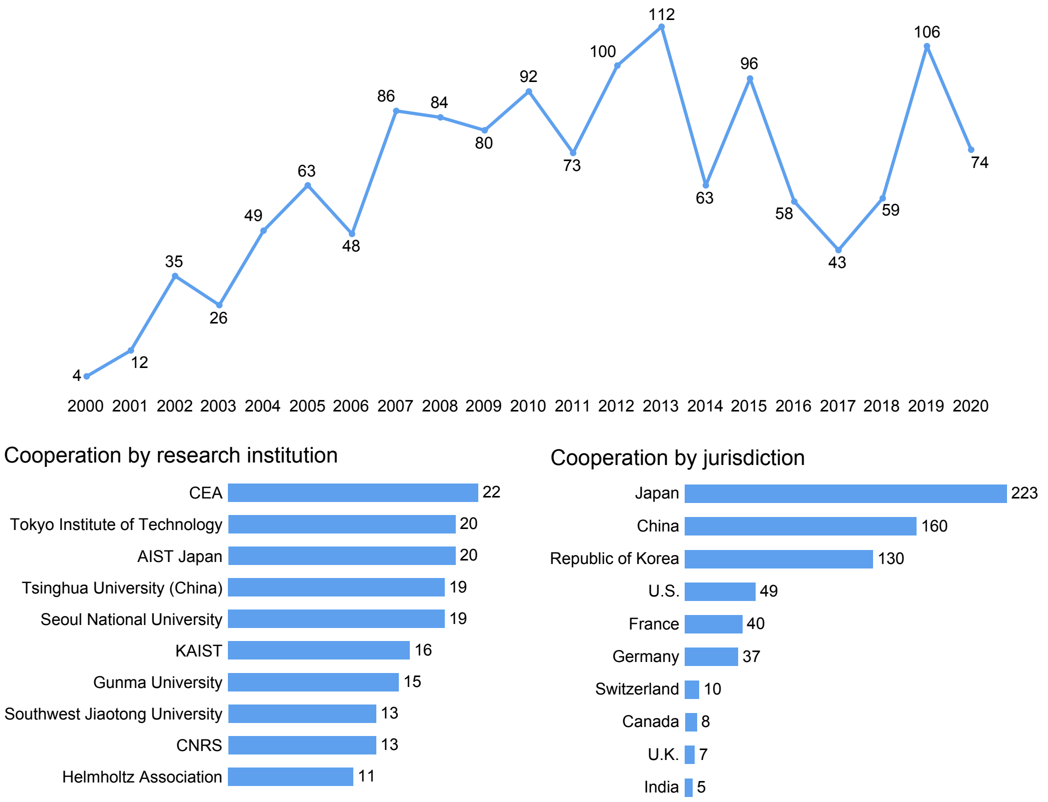
The analysis highlights the extent to which the high number of regularly active patent filing companies from China have been almost solely responsible for the remarkable increase in hydrogen fuel cell patent filings since 2015. Companies from other jurisdictions have either stagnated or been replaced by new entrants during the period in question, with no growth in the number of steadily active companies apart from those in China.

An overall increase in patent filings by universities and research institutes has encouraged cooperation with companies. Cooperative filings increased to more than 100 filings a year in 2020 (Figure 27). This is still relatively low compared to the total yearly filings by universities and research institutes. Total cooperative filings reached more than 1000 for the period 2000–2020 The drop in 2016 and 2017 was mainly due to a decline in cooperative filings from China. Japan, China and the Republic of Korea lead the jurisdictions in total filings. In terms of absolute patent cooperation by jurisdiction, Japan is in front, with a total of 223 cooperative filings between 2000 and 2020, followed by China (160) and the Republic of Korea (130). However, most of the cooperative filings from Japan are older, having been filed between 2000 and 2010, whereas those from China and the Republic of Korea are more recent, dating from mostly after 2010.

However, the French Alternative Energies and Atomic Energy Commission (CEA) is the leading institution in terms of total cooperation, followed by research institutes in Japan and the Republic of Korea. International research collaborations are few in number, with an average of five a year. It must be noted that out of a total of 64 universities and public research institutes involved in cooperative activities over the last 20 years, 38 percent are from China and 31 percent from the Republic of Korea. This goes to show that research institutes involved in cooperative activities in other jurisdictions are far more concentrated, with just a few players.

Cooperation of companies with universities and research institutes

Figure 27. **Cooperative filings increased steadily between 2000 and 2020.**
Applications filed in Japan have the highest number of cooperative filings.



Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: CEA is the French Alternative Energies and Atomic Energy Commission; CNRS is the Centre National de la Recherche Scientifique; KAIST is the Korea Advanced Institute of Science and Technology. There is an average 18-month delay between patent filing and publication. 2019 is the last year for which complete data are available.

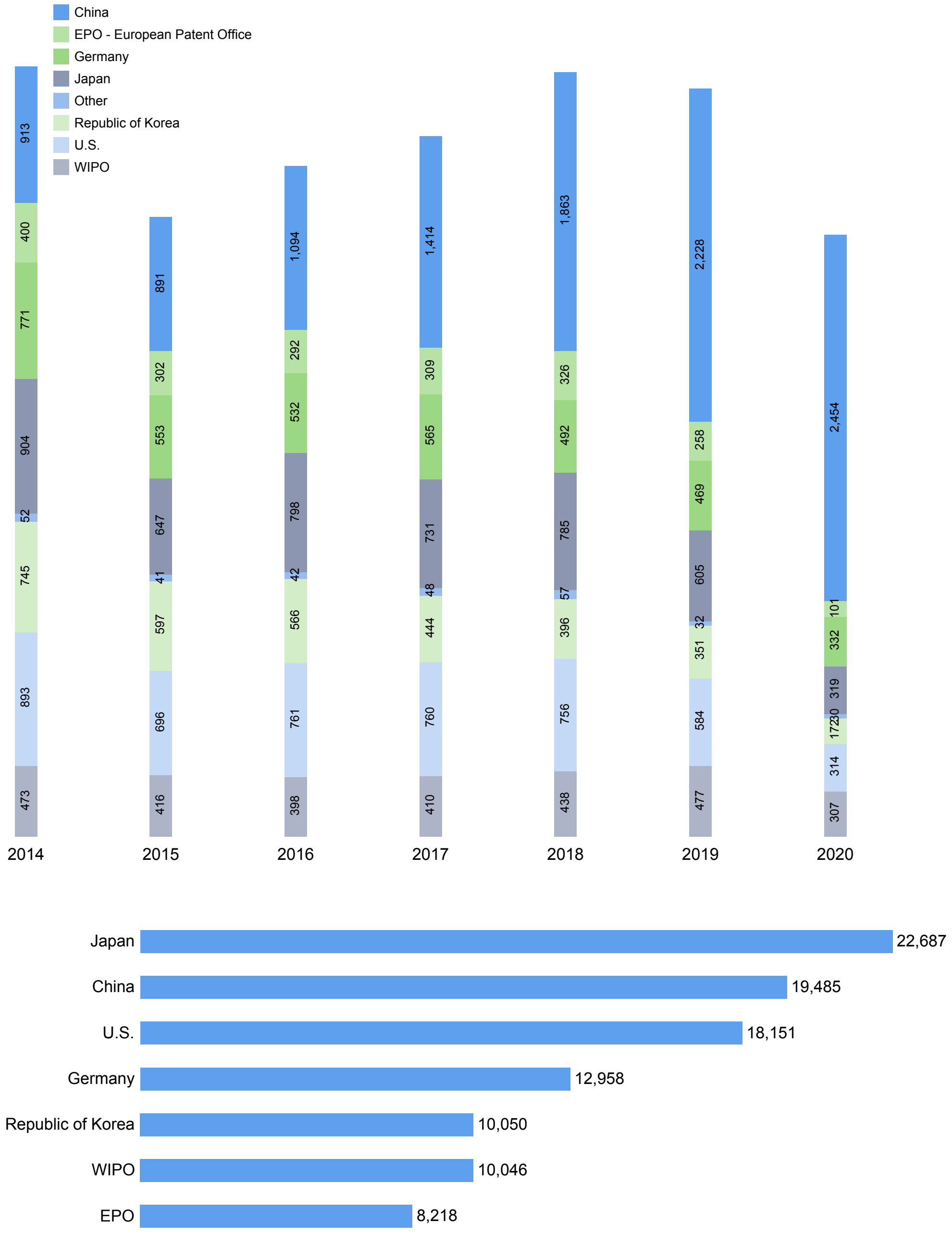
Market view analysis: where are fuel cell patents in transport being filed globally?

In what follows, we analyze the geographical scope of the patents filed. The analysis of filings across those patent offices where patent applications were filed provides a market view and highlights the patent protection strategy adopted by the average player. This describes an average trend in the jurisdictions where patent protection has mostly been sought. The patent strategies of particular companies would need to be individually analyzed in order to be understood and lie outside the scope of this study. This is the only part of the study where individual patent applications are analyzed rather than patent families.

Top patent offices for filing

Figure 28. Number of individual patent applications filed across top patent offices from 2014 to 2020 (top panel), and total number of patent applications filed in top patent offices until March 2022 (bottom panel).

Although the most number of patent applications have been filed in Japan, filings in China have been steadily increasing in the last few years.

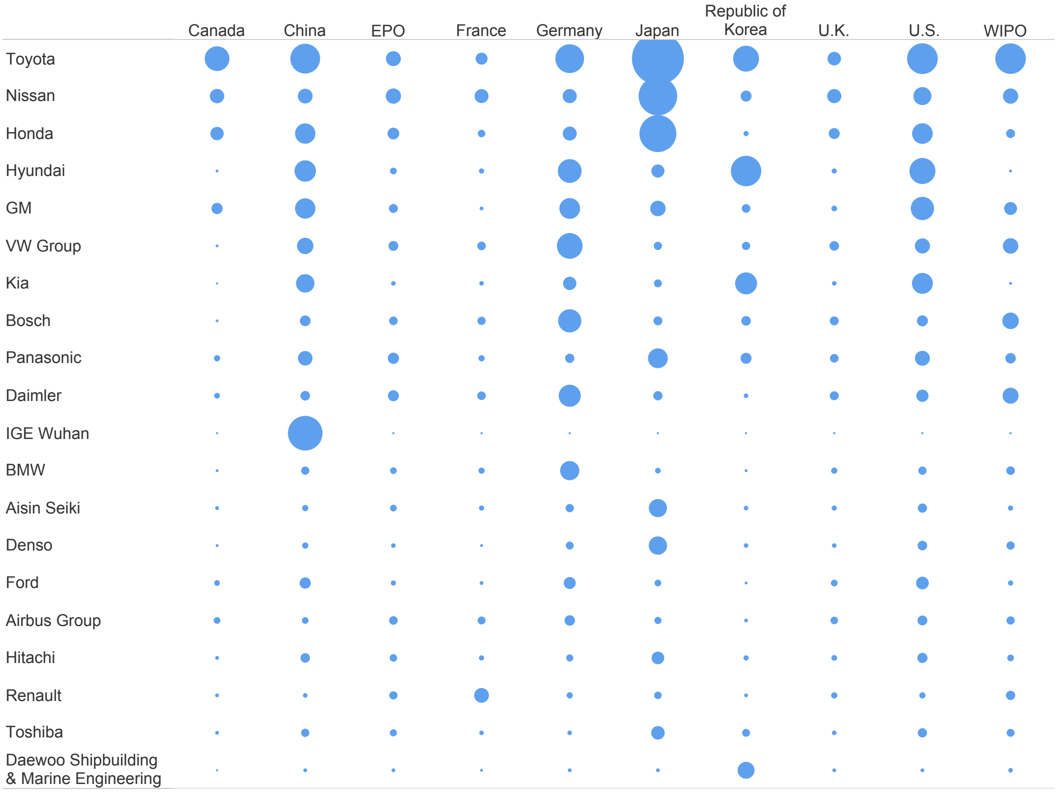


Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: EPO is the European Patent Office; WIPO is the World Intellectual Property Organization. WIPO represents PCT filings and the EPO EP filings. There is an average 18-month delay between patent filing and publication. 2019 is the last year for which complete data are available.

Top players and the patent offices where they filed patent applications

Figure 29. **Patent filing strategy by company. Bubble size indicates the total number of individual patent filings, limited to only filings from 2015 to 2019, including active and inactive patents as well as utility models.**

It is typical of companies to seek to protect their home market; for example, Toyota in Japan, VW Group in Germany and IGE Wuhan in China. It is, however, company strategy with regard to where in the world patent protection is extended that indicates the markets of most interest to these companies. In this respect, there is an obvious interest in China, the U.S., Japan, and also Germany and the Republic of Korea. Particularly of note is the number of PCT and EP filings, as this points to a broader, yet open strategy by some players.



Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: EPO is the European Patent Office; WIPO is the World Intellectual Property Organization.

Shifting the analysis from a patent filing count to active patent portfolios

While the analysis up to this point had been from the perspective of jurisdictions, we now shift attention to specific players in the field, namely, the individual companies and universities and research institutions. To this end, the indicators have been adjusted. While the focus in the global analysis was on filings, that is, on the annual filings in jurisdictions, the active patent portfolio is the subject of a company analysis. The active patent portfolio in question takes account of legal status and includes all active and pending patent applications, as well as active granted patents, at a given point in time. For example, in 2019, it includes all patents active in 2019, as well as all pending patents from 2019 and from previous years (see Glossary). The active patent portfolio allows an analysis of the strength of a company's patent portfolio, whereas filings show the dynamics. Therefore, in addition to the active patent portfolio, the filing activity of a company over the last few years is also shown below (utility models are disregarded when analyzing an active patent portfolio). The company analysis is therefore able to focus much more strongly on patent strength rather than solely on innovation activity. This is especially important in a field such as fuel cells, since older patents might have an important role once the market starts to develop but are very costly to maintain (i.e., in fees) over the long term – only players convinced of their success are willing to spend money in retaining such patents.

Basically, there is a clear correlation between the build-up of a strong active patent portfolio and active filing activity in recent years. Put another way, a declining active patent portfolio often goes hand-in-hand with a significant decrease in filing activity.

Table 2 shows the top 20 companies sorted by the size of their active patent portfolio in 2021. The top 20 list is dominated by automotive manufacturers. (As a side note, the first university to enter the field, the Chinese Academy of Sciences, ranks 22 overall.) Toyota is the leading company in fuel cells for transportation, with 2,720 active patent families in 2021, followed by Hyundai (1,402), Honda (1,191), General Motors (GM) (697) and VW Group (671). The dominance of Toyota is underlined by it having a portfolio almost twice the size of the runner-up (Hyundai) and an overall share of around 30 percent of the total portfolio of the top 10 ranked companies; a share that has remained relatively stable over time.

In addition, Table 2 includes a graphical representation of the development of the respective patent portfolios since 2000. This is intended to indicate a trend and is not normalized across all 20 companies. The portfolios of Honda and GM can also be seen be in decline, with Honda's portfolio declining by 20 percent since 2015. Conversely, VW Group's and Kia's portfolio has nearly tripled in size since 2015.

The top 20 is dominated by companies from Japan, Germany, the U.S., and the Republic of Korea. This is consistent with the analysis of key jurisdictions. What is striking is the clear under-representation of Chinese companies in the top 20, despite China being currently responsible for more than 50 percent of total filings. There are only two China-based companies in the top 20, IGE Wuhan (Chinese start-up *Grove-Auto.com*) and FAW Group, both with comparatively small portfolios, despite significant momentum. This can be explained by corporate structure. Although China has a majority of the companies active in this technology, their patent portfolios tend to be very small, with several like Great Wall Motors (GWM) and Dongfeng having started to file only very recently.

Table 2. Top 20 companies in fuel cells for transportation in general.

Active patent portfolios of the leading 20 players in fuel cells in road transport compared to recent patent filing activity (all patents, active and inactive).

Company	Active patent portfolios	2000	2005	2010	2015	2019	2021	2015	2016	2017	2018	2019
Toyota		132	782	1,919	1,734	2,319	2,720	130	260	265	328	216
Hyundai		29	103	398	821	1,206	1,402	109	161	84	93	113
Honda		52	610	1,217	1,323	1,232	1,191	90	108	58	87	94
GM		37	247	631	815	802	697	22	23	29	17	11
VW Group		16	91	131	206	471	671	64	64	83	122	109
Kia		8	18	65	184	380	576	26	54	76	90	107
Nissan		73	728	617	636	633	540	57	39	24	14	16
IGE Wuhan		0	0	0	0	97	489	0	3	17	35	113
Bosch		53	93	132	241	300	479	25	26	42	56	108
Denso		23	194	221	235	271	301	19	29	43	30	32
Panasonic		59	213	292	293	265	267	16	17	24	19	26
BMW		5	25	51	99	255	250	33	60	64	14	18
Ford		8	56	115	184	243	217	24	24	27	17	11
Volvo		4	12	40	106	176	197	33	21	12	13	14
Daewoo Shipbuilding & Marine Engineering		0	1	8	75	159	189	48	39	23	25	15
Daimler Truck		0	3	18	87	161	182	32	21	10	13	12
LG Chem		1	10	59	119	175	175	15	20	12	7	0
Airbus Group		4	23	83	158	138	156	5	6	6	10	21
FAW Group		0	0	0	58	81	153	0	0	4	8	56
State Grid Corp		0	11	69	108	129	144	5	6	5	12	11

Source: WIPO, based on patent data Lexis Nexis PatentSight up to March 2022.
Note: To analyze the activity of companies we measure the number of active patents in the respective year (cumulative active patent portfolio, left) as well as the filing activity of these players by counting how many patents were first filed in the respective years (counting all patents, inactive and active, right).

Dynamic and comparative company analysis

Since global patent numbers rise continually, an increase in a company's patents per technology indicates increased patent activity but is not in itself a sign of growing competition within this technology. Increased activity can be offset by an even higher degree of activity by a competitor in the field. However, if one puts the patent activity of a company in relation to patent activity worldwide, it is possible to derive the world share of a particular company in a technology. This shows the importance of a company with respect to the global dynamics of a technology, and at the same time its comparative competitiveness in relation to other companies. Figure 30 uses a dynamic and comparative indicator developed by EconSight to highlight the competitive situation between companies in the field of fuel cell transport.

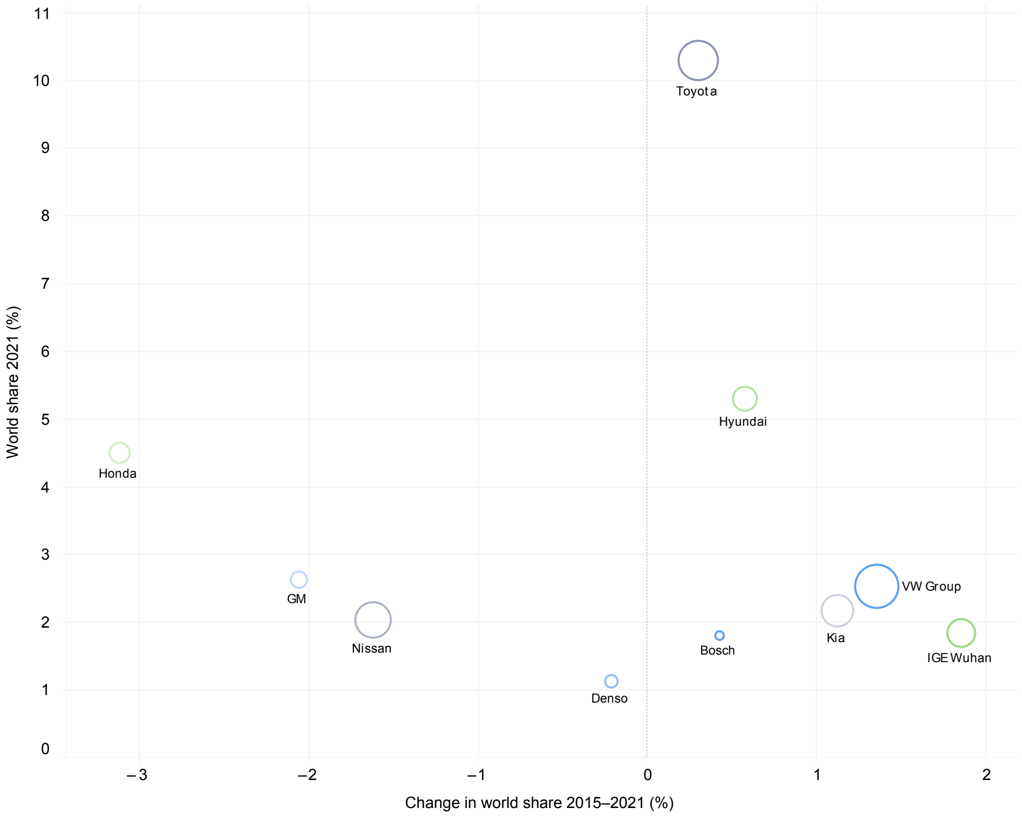
The development of world share over several points in time shows an increase or decrease in a company's competitiveness over time. Instead of using growth rates (which, even with the same absolute change in patent numbers, are mathematically smaller when applied to larger shares than when applied to smaller ones), time series analysis focuses on change in the world share in percentage points. This indicator shows the size of the change and adequately describes the increase (or decrease) in a company's technological activities in relation to the competition.

In this sense, Figure 30 shows Toyota's dominance in terms of a world share of 10 percent of the global total active patent portfolios in fuel cell transport, followed by Hyundai, with about half of Toyota's world share (5.5 percent). Additionally, the slowing momentum of Honda, Daimler, GM and Nissan is evident, shown here as a negative change in world share between 2015 and 2021, and affecting all companies to the left of the vertical axis. Conversely, those companies with the greatest momentum are shown on the right of the vertical axis, with growing world shares, namely, VW Group, Kia and IGE Wuhan.

World share of active patents by company in 2021 compared to all players in the field versus the change in this world share, 2015–2021

Figure 30. **World shares and change in world shares in transport during the period 2015–2021 for the top 10 companies.**

The proportion of active patents of companies like Toyota and Hyundai have increased in the last few years whereas those of companies like Honda, GM, and Nissan have decreased.



Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

By analyzing the world share in 2021 (meaning the share of active patents contributed by an entity (here a company) over all patents for the field) versus the change in this share between 2015 and 2021, we are able to see which companies increased their shares and therefore grew their portfolios more successfully than other players. Every company left of the vertical zero percent line saw a decline in its world share, whereas companies to the right of the zero percent line increased their world share or were more active during this period. Thus, the world shares of Honda, GM and Nissan have shrunk, whereas those of Hyundai, Toyota, VW Group and IGE Wuhan have expanded.

Top 20 universities and research institutes in the field

The first university to enter the overall fuel cells in transport field, the Chinese Academy of Sciences, ranks 22 overall. This is an indication of just how dominant commercial players are within the field. Nevertheless, the activity of universities is not to be underestimated. The academic field is largely dominated by Chinese universities, followed by universities in the Republic of Korea and Japan. A close-up of patents not invented (based on the inventors' location) in either China, the Republic of Korea or Japan shows the leading academic players in Europe and North America to be, from the top, the French Atomic and Renewable Energy Agency (CEA), followed by the German Helmholtz Association and the German Aerospace Center, then Batelle Memorial Institute and Fraunhofer with the same number of filings, and the Centre National de la Recherche Scientifique (CNRS) in France.

Top universities and research institutions in fuel cells in transport, globally, in Europe and North America

Table 3. **Active patent portfolios (without utility models) of top-ranked universities and research institutions in fuel cells in transport.**

Global view of leading players; focused view of universities and research institutions from Europe (47 jurisdictions) and North America (16 jurisdictions) (by inventor's address).

Global Universities		Europe		North America	
Research Institute	**Patent portfolio size 2021**	**Research Institute**	**Patent portfolio size 2021**	**Research Institute**	**Patent portfolio size 2021**
Chinese Academy of Sciences	121	CEA	55	Battelle	21
Tsinghua University (China)	88	Helmholtz Association	33	MIT	11
Jilin University	80	Fraunhofer	21	University of Chicago	11
Tongji University	79	CNRS	17	University of California	10
Southwest Jiaotong University	63	University of Chester	14	State University of New York	8
Wuhan University of Technology	61	Paul Scherrer Institute	5	University of New Mexico	8
CEA	58	Technical University of Denmark	3	Lawrence Livermore National Security	7
KIST Korea	54	Joseph Fourier University	3	State University System of Florida	7
Korea Institute of Energy Research	51	VTT Technical Research Centre	3	University System of Ohio	6
Helmholtz Association	46	Max Planck	3	Stanford University	6
KAIST	42	ZSW	3	University of Tennessee	6
Jiangsu University	41	University of Jena	3	University of Michigan	5
Zhejiang University	34	TNO Netherlands	2	University of Texas System	5
Beijing Institute of Technology	32	Dresden University of Technology	2	Syracuse University	5
Seoul National University	31	ETH Zurich	2	Caltech	5
Nanjing University of Aeronautics and Astronautics	29	University of Rennes 1	2	University of Missouri System	4
Harbin Institute of Technology	29	Berlin Institute of Technology	2	Colorado School of Mines	3
ITRI	28	Clausthal University of Technology	2	Purdue University	3
Agency for Defense Development	28	Riga Technical University	2	University of Houston System	3
Harbin Engineering University	28	Technical University Munich	2	Washington State University	3
Xi´an Jiaotong University	28	Politehnica University of Bucharest	2	University of South Carolina	3
Tianjin University	25	National Polytechnic Institute of Toulouse	2	Northwestern University (Illinois)	3
Korea Inst. of Ocean Sci. & Tech.	25	Community Grenoble Alpes University	1	University of North Carolina	2
Huazhong Univ. of Sci. & Tech.	24	IRD France	1	Yale University	2
AIST Japan	22	Poznan University of Technology	1	Virginia Tech	2

Note: CEA is the French Alternative Energies and Atomic Energy Commission; CNRS is the Centre National de la Recherche Scientifique; INTRI is the Industrial Technology Research Institute; KAIST is the Korea Advanced Institute of Science and Technology; KIST Korea is the Korea Institute of Science and Technology; MIT is the Massachusetts Institute of Technology; ZSW is Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg.

Fuel cell application: personal and commercial road vehicles

The road transport sector needs to decarbonize and dramatically lower emissions. This is necessary not just from a regulatory perspective, but also because only a truly sustainable transportation and automotive industry will be able to maintain its importance and prosperity in the long term.

Moving to a Net Zero-emission future creates crucial challenges for the automotive industry. The introduction of alternative power trains and their related energy concepts is becoming a choice between battery electric vehicles (BEVs) and FCEVs powered by hydrogen.

Hydrogen has long been known as a low-carbon fuel, although establishing it in the automotive industry has been difficult. To date, hydrogen use in the sector has been limited to a less than 1 percent share of the total global stock of vehicles. However, the fuel cell vehicle market is beginning to take off, catalyzed by developments in Asia and the United States. More than 40,000 fuel cell vehicles were on the road globally by the end of June 2021. Global fuel cell vehicle deployment has been concentrated largely on passenger vehicles.

Active patent portfolio development of the most intensively patenting Chinese car manufacturers in fuel cells

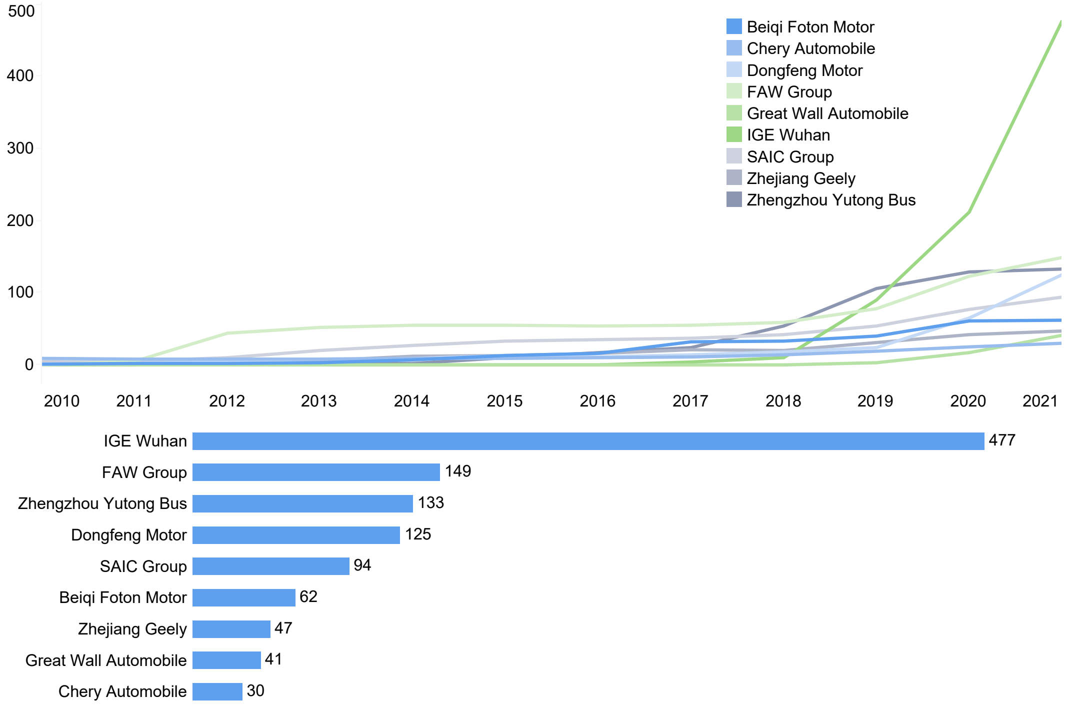
However, there are differences in the geographical distribution of the various fuel cell vehicle types. In particular, the Republic of Korea, the United States and Japan have focused efforts on passenger vehicles, whereas China has adopted policies supporting fuel cell bus and commercial vehicles such as trucks. This trend is likely to continue, as the new Chinese policy of subsidizing fuel cell vehicles is intended to enhance the manufacturing capacities of China's fuel cell vehicle industry with a focus on using fuel cells in commercial vehicles (S&P Global, 2020). Hydrogen fuel cells offer great promise for heavy-duty trucks in applications requiring a higher density of energy, fast refueling and additional range. The Toyota Mirai, for instance, achieved an unprecedented 1,360 km driven on a single, five-minute complete fill of hydrogen during a roundtrip of southern California (Toyota, 2021). Recently, Renault previewed a concept vehicle with what it termed a "hydrogen engine," suggesting that this French company could follow Toyota in using hydrogen as a means of preserving and advancing existing combustion technology with low carbon fuel (AutoCar, 2022).

Dongfeng has independently developed a 12-ton hydrogen fuel cell logistics vehicle to meet both intra- and inter-city logistics needs. In 2021, Dongfeng Motor put into operation a fleet of Dongfeng Tianlong KL tractor trucks running on 20 hydrogen fuel cells in Hebei Province, China (H2 Bulletin, 2021). Commercial vehicle-maker Beiqi Foton Motor (a subsidiary of BAIC) is aiming to manufacture 4,000 hydrogen vehicles per year by 2023, before raising the bar to 15,000 units by 2025 (Carscoops, 2020). Moreover, China-based GWM released its hydrogen energy strategy (Green Car Congress, 2021), making the bold claim: "2022 will see the first service fleet of high-end passenger cars on the arena of the Olympic Winter Games; in 2023, we will become a leader domestically in terms of the number of core power components promoted; we will ride into the top three in terms of global hydrogen market share by 2025." Currently, GWM has remained completely independent of other players in terms of IP rights and its development of IP in respect to the six core technologies and products of stack and core components – fuel cell engines and components (controllers, and so on); hydrogen storage cylinders; high-pressure hydrogen storage valves; hydrogen safety; and liquid hydrogen – with all patenting exclusively by Great Wall and no collaboration visible. SAIC Motor, China's biggest automaker – and a partner of Volkswagen and GM – has said it plans to sell over 10,000 hydrogen fuel cell vehicles by 2025 (Reuters, 2020a).

IGE Wuhan is a scientific and technological innovation development platform jointly established by Wuhan City and China University of Geosciences (Grove, 2021). IGE, the parent company of Grove, is China's leading group in terms of hydrogen vehicle production, development and maintenance. It is also the parent company of Wuhan Tiger, a heavy vehicle, hydrogen fuel cell power-train company. This ecosystem allows Grove to support the development of not only hydrogen mobility but also the entire hydrogen vehicle industry. At the 2021 Shanghai Motor Show, Grove revealed that it is developing long range vehicles, with a first batch of cars capable of driving over 1,000 km on a single tank of fuel and taking only a few minutes to refuel. Grove has already received 3,500 orders for its hydrogen energy heavy-duty trucks (China University of Geoscience, 2021).

Figure 31. Comparison of the most active patenting Chinese car manufacturers based on active patent portfolio data, 2010–2021.

IGE, China's leading group in terms of hydrogen vehicle production, development and maintenance, also leads in patent filings.

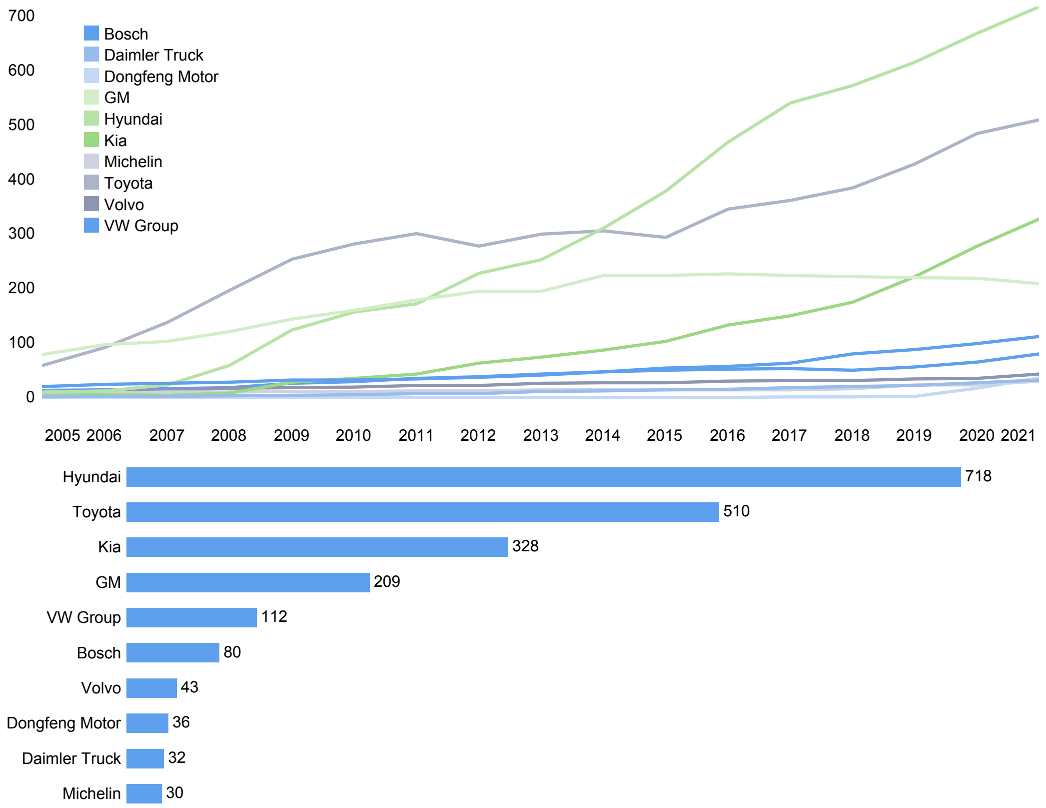


Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

Active patent portfolio development of the most active global truck manufacturers in fuel cells

In Europe, numerous announcements made in 2020 signal a greater effort in deploying fuel cell buses and trucks. Although almost every major manufacturer worldwide is working on the technology, only a few trucks and buses from Hyundai and Toyota are ready for series production. In 2021, Hyundai delivered 46 heavy-duty trucks to Switzerland and expects to become the first global automaker to apply its fuel cell system to all its commercial vehicle models by 2028. A total 62 companies, including Daimler, Iveco, Michelin, Shell and Total, have agreed to put 100,000 hydrogen trucks on the road throughout Europe by 2030 (Green Tech Media, 2020). Daimler Trucks is testing its GenH2 long-haul truck which uses liquid hydrogen to generate electric power from a fuel cell; the vehicle could be ready for use by 2027, if the hydrogen fuel infrastructure is ready (Daimler Trucks, 2021). Iveco and Nikola have confirmed plans to launch hydrogen fuel cell trucks by the end of 2023, as part of a deeper push into alternative fuels by the commercial vehicle industry in the U.S. market (Reuters, 2021a). To this end, Nikola has partnered with auto supplier Robert Bosch to jointly develop fuel cell technology for use in its semi-truck FCEV (*Automotive World*, 2021). In the Chinese market, Hyundai is starting out with hydrogen heavy trucks and will then move into passenger vehicles, aiming to have more than 30,000 FCEVs on Chinese roads within the next four years (*China Daily*, 2022).

Figure 32. **Comparison of the most active patenting global truck and commercial vehicles manufacturers based on active patent portfolio data, 2005–2021.**
Hyundai, which has already delivered hydrogen fuel cell-powered trucks to Switzerland, leads in patent filings.



Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

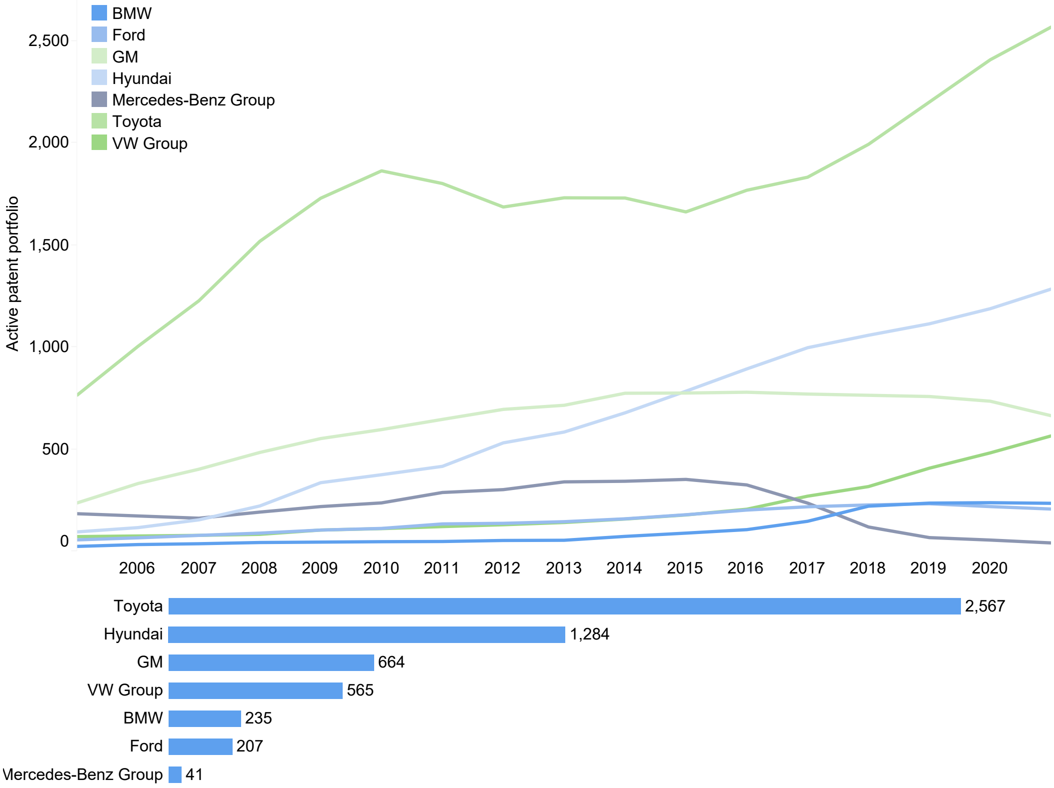
Meanwhile, Bosch is focusing on the growing market for the latest hydrogen megatrend – green hydrogen. The company believes European Union market will be worth almost 40 billion euros by 2030, with annual growth rates of 65 percent (Fuel Cell Works, 2021a). Fuel cells convert hydrogen into electricity, and Bosch is developing both stationary and mobile fuel cell solutions. From 2021 to 2024, the company plans to invest 1 billion euros in fuel cell technology – “Bosch is already H_2-ready” the CEO of Bosch has declared.

Whereas the world’s biggest passenger vehicle manufacturers (VW by volume and Tesla by value) are directing their focus exclusively on BEVs, the second-largest, Toyota (plus Hyundai and some others), has put fuel cell vehicles at the core part of its strategy (Arthur D. Little, 2021). BMW, Daimler and GM have taken a middle path and chosen to manage a dual strategy.

Active patent portfolio development of the leading global automotive producers in fuel cells

Figure 33. Active patent portfolios of the leading global automotive producers in fuel cells, 2006–2021.

By far the largest active patent portfolio in fuel cells belongs to the automaker Toyota.

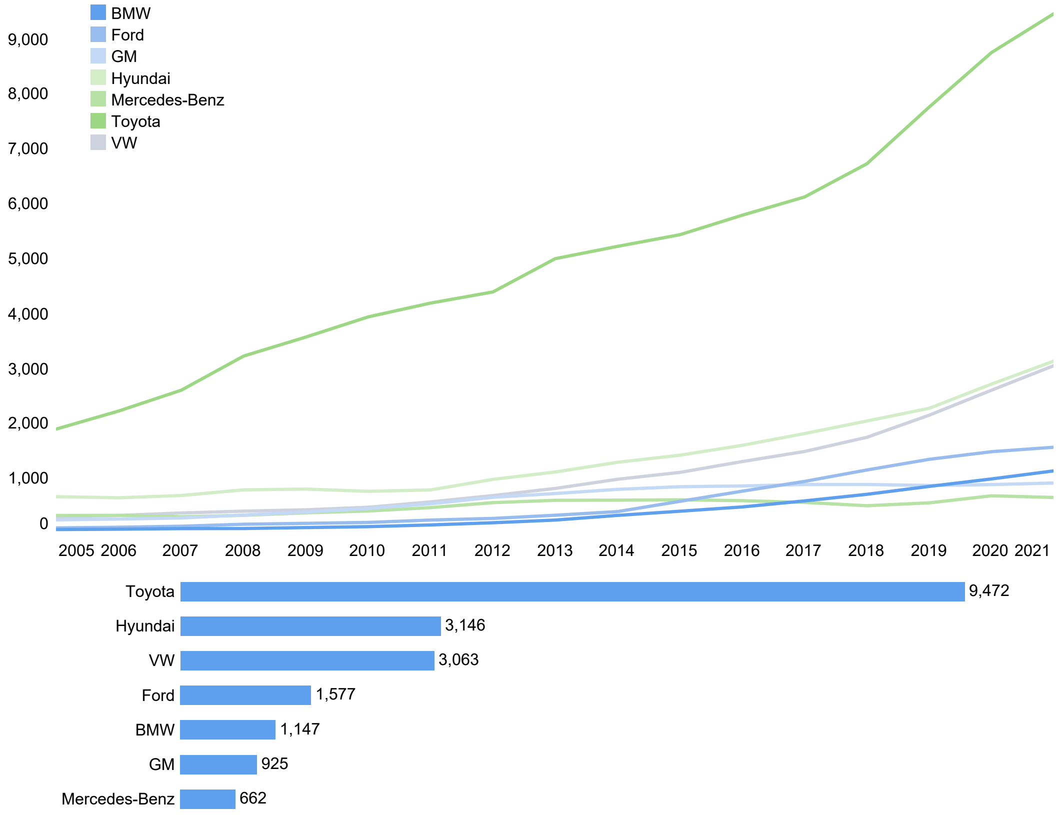


Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

Active patent portfolio development of the leading global automotive producers of electric vehicles

Figure 34. Active patent portfolios of the leading global automotive producers of electric vehicles, 2005–2021.

Toyota has the largest active patent portfolio among automotive producers in electric vehicles, similar to that in fuel cells.



Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

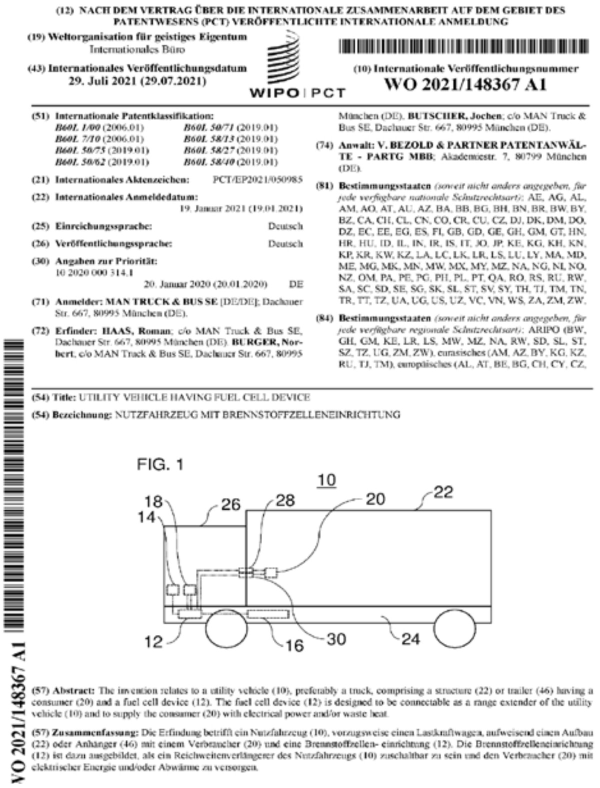
When comparing the patent portfolio development of the leading car manufacturers in fuel cells for electric vehicles (excluding hybrids), it becomes immediately obvious just how important electric vehicles are currently compared to fuel cell vehicles. Most manufacturers have at least three (Hyundai, BMW, Daimler), four (Toyota), five (Ford) or even 10 times more electric vehicle patents active in their portfolio than fuel cell patents.

Based on current and declared future capacity, the IEA estimates that fuel cell manufacturing could enable a stock of 6 million FCEVs by 2030, satisfying around 40 percent of the need, according to the IEA Net Zero Emissions by 2050 Scenario (IEA, 2021b).

Fuel cells as range extender

A realistic scenario for fuel cells in transport would seem to be as a cooperative solution with batteries rather than an alternative. In this scenario, fuel cells are used to generate – on-site or on-board – electricity with which to feed a battery likewise installed on-site, and this battery is what drives the vehicle. The fuel cell is a sort of range extender for the battery. The battery could be smaller and lighter than needed to meet full energy demand, while the fuel cell – be it hydrogen, methanol or ammonia – could be easily reloaded. Range extenders are specifically discussed in applications for commercial, heavy or long-distance cargo transport (see for example Wu *et al*., 2019).

Figure 35.1 Patent example: MAN Truck patent application, WO2021148367. Utility vehicle having fuel cell device.



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(71) Anmelder: **MAN TRUCK & BUS SE** [DE/DE]; Dachauer Str. 667, 80995 München (DE).

(72) Erfinder: **HAAS, Roman**; c/o MAN Truck & Bus SE, Dachauer Str. 667, 80995 München (DE). **BURGER, Norbert**; c/o MAN Truck & Bus SE, Dachauer Str. 667, 80995 München (DE). **BUTSCHER, Jochen**; c/o MAN Truck & Bus SE, Dachauer Str. 667, 80995 München (DE).

(74) Anwalt: **V. BEZOLD & PARTNER PATENTANWÄLTE - PARTG MBB**; Akademiestr. 7, 80799 München (DE).

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(54) Title: UTILITY VEHICLE HAVING FUEL CELL DEVICE

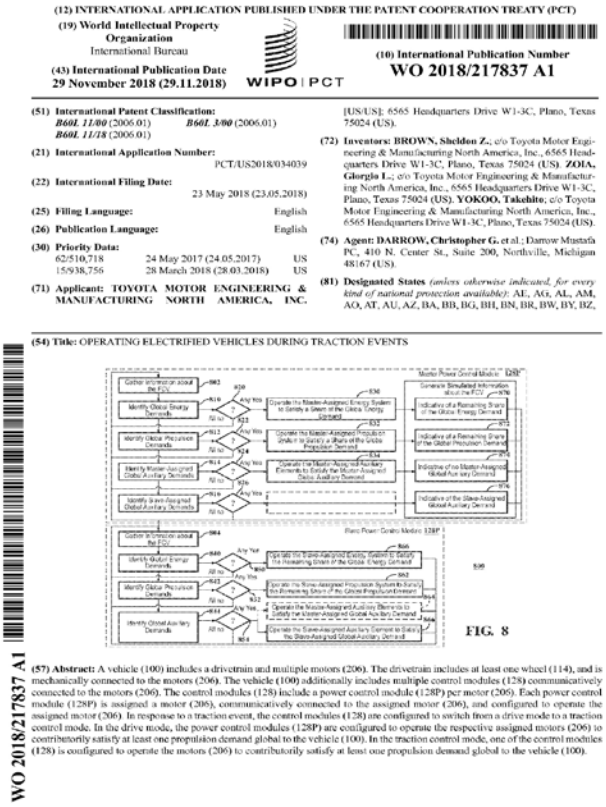
(54) Bezeichnung: NUTZFAHRZEUG MIT BRENNSTOFFZELLENEINRICHTUNG

(57) Abstract: The invention relates to a utility vehicle (10), preferably a truck, comprising a structure (22) or trailer (46) having a consumer (20) and a fuel cell device (12). The fuel cell device (12) is designed to be connectable as a range extender of the utility vehicle (10) and to supply the consumer (20) with electrical power and/or waste heat.

(57) Zusammenfassung: Die Erfindung betrifft ein Nutzfahrzeug (10), vorzugsweise einen Lastkraftwagen, aufweisend einen Aufbau (22) oder Anhänger (46) mit einem Verbraucher (20) und eine Brennstoffzellen- einrichtung (12). Die Brennstoffzelleneinrichtung (12) ist dazu ausgebildet, als ein Reichweitenverlängerer des Nutzfahrzeugs (10) zuschaltbar zu sein und den Verbraucher (20) mit elektrischer Energie und/oder Abwärme zu versorgen.

VO 2021/148367 A1

Figure 35.2 Patent example: Toyota, WO2018217835. Fuel cell vehicle with power modules.



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15/938,756 28 March 2018 (28.03.2018) US

(71) Applicant: **TOYOTA MOTOR ENGINEERING & MANUFACTURING NORTH AMERICA, INC.** [US/US]; 6565 Headquarters Drive W1-3C, Plano, Texas 75024 (US).

(72) Inventors: **BROWN, Sheldon Z.**; c/o Toyota Motor Engineering & Manufacturing North America, Inc., 6565 Headquarters Drive W1-3C, Plano, Texas 75024 (US). **ZOIA, Giorgio L.**; c/o Toyota Motor Engineering & Manufacturing North America, Inc., 6565 Headquarters Drive W1-3C, Plano, Texas 75024 (US). **YOKOO, Takehito**; c/o Toyota Motor Engineering & Manufacturing North America, Inc., 6565 Headquarters Drive W1-3C, Plano, Texas 75024 (US).

(74) Agent: **DARROW, Christopher G.** et al.; Darrow Mustafa PC, 410 N. Center St., Suite 200, Northville, Michigan 48167 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,

(54) Title: OPERATING ELECTRIFIED VEHICLES DURING TRACTION EVENTS

(57) Abstract: A vehicle (100) includes a drivetrain and multiple motors (206). The drivetrain includes at least one wheel (114), and is mechanically connected to the motors (206). The vehicle (100) additionally includes multiple control modules (128) communicatively connected to the motors (206). The control modules (128) include a power control module (128P) per motor (206). Each power control module (128P) is assigned a motor (206), communicatively connected to the assigned motor (206), and configured to operate the assigned motor (206). In response to a traction event, the control modules (128) are configured to switch from a drive mode to a traction control mode. In the drive mode, the power control modules (128P) are configured to operate the respective assigned motors (206) to contributorily satisfy at least one propulsion demand global to the vehicle (100). In the traction control mode, one of the control modules (128) is configured to operate the motors (206) to contributorily satisfy at least one propulsion demand global to the vehicle (100).

WO 2018/217837 A1

The ranking of the top companies in road applications corresponds to the above findings (Table 4). Toyota is top, with its 2,571 active patents in 2021 accounting for about 40 percent of the total patents held by the top five companies. The top 10 is comprised entirely of automotive manufacturers and suppliers, and is followed in 11th position by Panasonic, the highest ranking non-automotive player.

No general trend can be discerned among the different players. Some manufacturers, such as GM, Nissan and Honda, have decreasing active patent portfolios and declining numbers of filings in recent years; others, such as Hyundai, Kia, VW and Volvo, have expanded their portfolios. New market entrants are IGE Wuhan, Zhengzhou Yutong Bus, and Weichai Power.

Top companies in transport in road applications, active patent portfolio and filing development

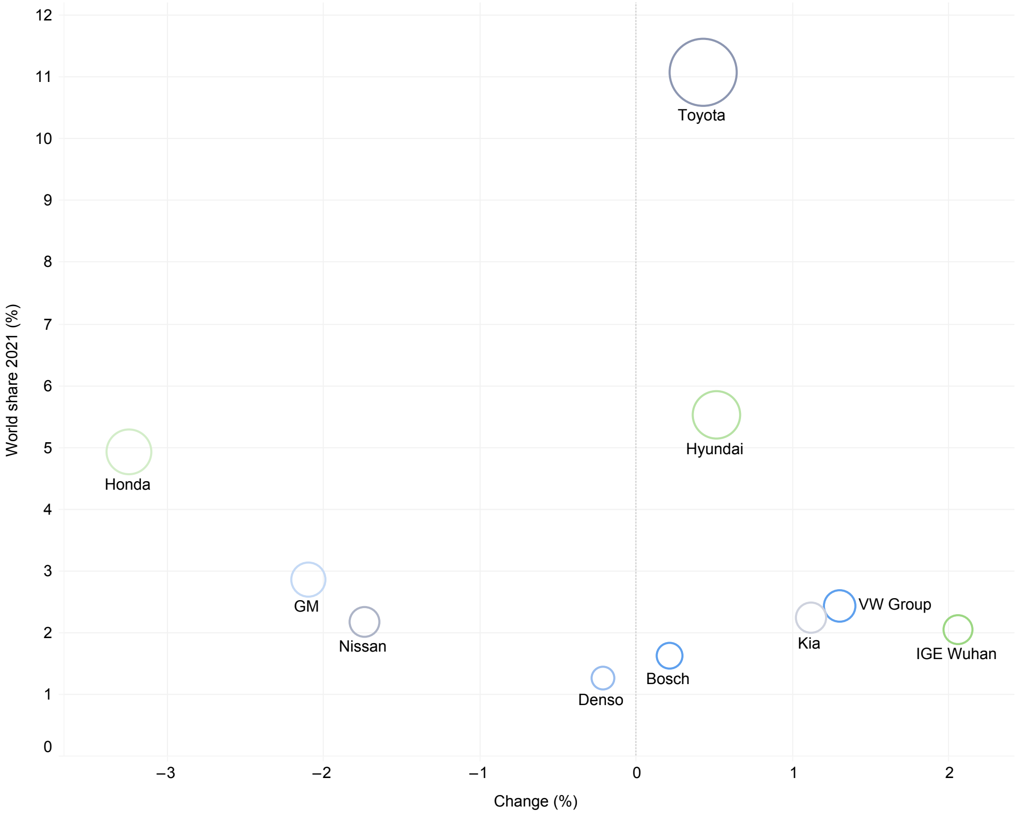
Table 4. **Active patent portfolios of the leading 20 players in fuel cells in road transport (left part of table) compared to recent patent filing activity (all patents, active and inactive, right part of table).** *Leading players Toyota and Hyundai not only have the largest active patent portfolios but have also increased it in recent years.*

Company	Active patent portfolios	2000	2005	2010	2015	2019	2021	2015	2016	2017	2018	2019
Toyota		129	765	1,863	1,663	2,201	2,571	125	246	246	307	204
Hyundai		23	95	375	784	1,114	1,284	97	134	71	76	104
Honda		51	592	1,180	1,277	1,185	1,145	87	105	56	85	94
GM		35	237	596	775	759	665	21	21	24	16	10
VW Group		15	72	111	178	408	566	57	57	73	103	85
Kia		6	16	64	177	351	522	25	45	67	74	99
Nissan		69	712	597	612	600	506	54	35	20	13	13
IGE Wuhan		0	0	0	0	90	477	0	3	10	35	113
Bosch		46	86	120	222	265	379	19	22	31	47	71
Denso		21	187	218	232	266	295	19	27	43	30	31
Panasonic		55	204	281	282	257	259	15	17	22	19	24
BMW		5	24	47	89	236	235	31	56	62	14	15
Ford		8	56	112	179	234	208	22	22	26	17	11
LG Chem		0	9	56	111	167	167	14	20	12	7	0
FAW Group		0	0	0	55	78	149	0	0	4	8	56
Volvo		4	11	31	80	126	144	23	12	9	10	12
Weichai Power		0	0	0	1	46	134	1	0	5	12	78
Zhengzhou Yutong Bus		0	0	0	10	106	133	10	13	48	42	15
Suzuki		6	29	57	86	125	131	18	15	8	2	7
Daimler Truck		0	3	12	64	112	129	23	12	7	10	10

In the competitive environment shown in Figure 36, Toyota and Hyundai lead the field in terms of world share of fuel cells for road applications; furthermore, they have managed to increase their world share in recent years. In contrast, the companies immediately behind in the ranking, namely, Honda, GM and Nissan, have each been losing world share. Toyota and Hyundai can therefore be expected to extend their lead in this application in the coming years. VW Group, Kia and IGE Wuhan are three companies whose growth in the field is noteworthy. All three are catching up, and have recorded an increase in world share higher than either Toyota or Hyundai.

Top 10 companies’ world shares in road applications, 2015–2021

Figure 36. World shares and change in world shares between 2015–2021 for the top 10 companies.
Toyota leads the world in road applications, and has increased its share in the last few years.



Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

As Figure 36 shows, the world shares of Honda, GM and Nissan have all shrunk, whereas those of Toyota, Hyundai, VW Group, Kia and IGE Wuhan have grown.

Fuel cell application: shipping and marine vehicles

Shipping makes a significant contribution to global greenhouse gas emissions – around 2.5 percent – and a majority of ocean, coastal and inland vessels continue to run on heavy fuel oil and diesel, many even without exhaust gas treatment. Thus, the International Maritime Organization is targeting the decarbonization of maritime fuels, especially through the use hydrogen, methanol and ammonia. According to the Global Maritime Forum, to fully decarbonize international shipping by 2050, hydrogen and ammonia will be needed to help replace the 250–300 million tonnes of oil the industry burns every year (Bloomberg, 2021). Hydrogen-based fuels, particularly ammonia, are attracting attention for use in large sea-going vessels. Major industry stakeholders like Wärtsilä have announced plans to make 100 percent ammonia-fuelled maritime engines available as early as 2023, and to offer ammonia retrofit packages for existing vessels from 2025. According to the IEA Net Zero Emissions by 2050 Scenario, ammonia meets 8 percent of total shipping fuel demand and hydrogen 2 percent. One of the largest manufacturers of marine engines, the MAN Group, is researching intensively into ammonia technologies (Market Research Telecast, 2021).

Maersk, on the other hand, is focusing on methanol-fueled ships (Bloomberg, 2021). New vessels built by Hyundai Heavy Industries Co. represent about 3 percent of Maersk's total container capacity. These will replace older ships in the company's fleet, saving about 1 million tonnes of CO_2 emissions a year. Maersk has the option for four more of the ships to be delivered in 2025. Shell will collaborate in a feasibility study trialing the use of hydrogen fuel cells to power ships, the first of its kind for the company. If successful, it would help pave the way for cleaner, hydrogen-powered shipping. Shell, which is the charterer of the trial vessel and the hydrogen fuel provider, is working together with SembCorp Marine Ltd and its wholly-owned subsidiary LMG Marin AS, which will design the fuel cell and retrofit the vessel, as well as Penguin International, the owner of the roll-on/roll-off vessel (Shell, 2021).

In 2022, ABB with leading experience in marine solution announced it is to join forces with Ballard Power, a company with expertise in the development of megawatt-scale fuel cell systems for land-based use, to take the next step in making this technology available for larger vessels (ABB, 2022).

In 2021, AIDA Cruises was to be the first cruise company in the world to test fuel cells on a large passenger ship as part of the "Pa-X-ell2" research project on-board the *AIDAnova* (Carnival, 2021). In addition to AIDA Cruises (represented by Carnival Maritime GmbH), the Meyer Werft shipyard, Freudenberg Sealing Technologies and other partners are involved in a joint project funded by the German Federal Ministry of Transport and Digital Infrastructure. The project's objective is to find practical solutions for climate-neutral mobility across all shipping. The groundbreaking "Pa-X-ell2" project specifically aims to develop a decentralized energy network and a hybrid energy system with a new generation of fuel cells for use in ocean-going passenger vessels.

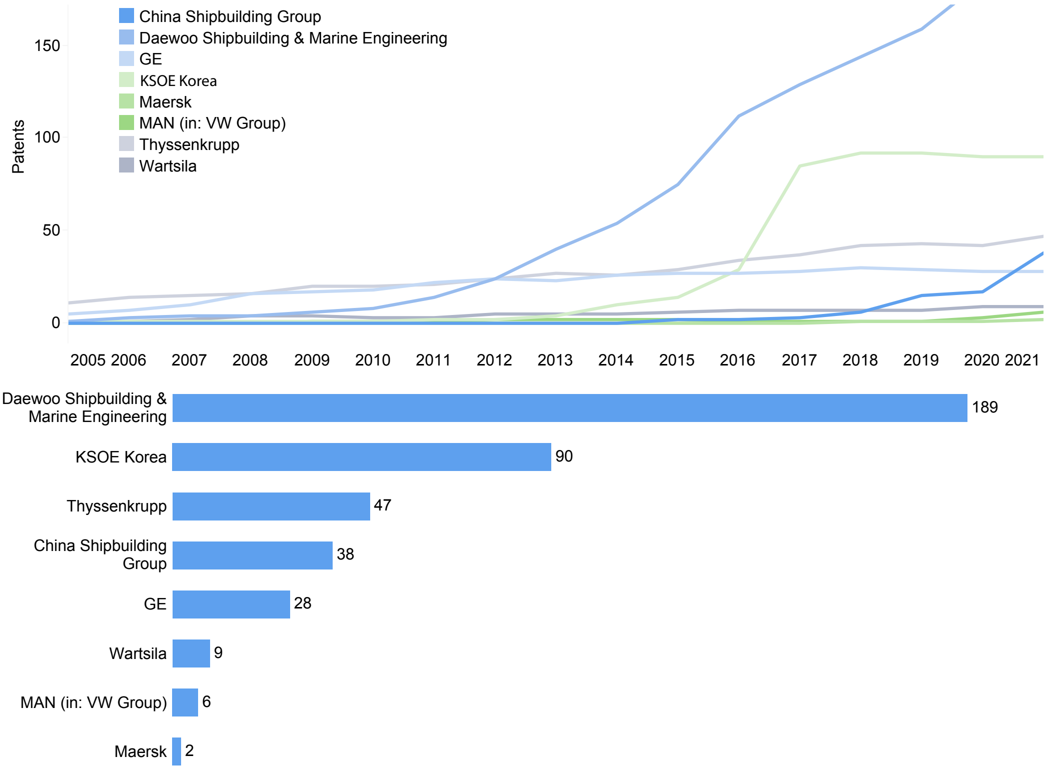
Although hydrogen fuel cells have been trialled on several short-distance vessels, they are not yet commercially available (Xing *et al.*, 2021). However, the commercial operation of fuel cell ferries was expected to begin in 2021 in the U.S. and Norway. The Danish ferry shuttle firm DFDS hopes that by 2027 a new ship, *Europa Seaways*, will operate between Copenhagen and Oslo, powered by compressed hydrogen and emitting only clean water (*Wired*, 2021).

Major retailers, including Amazon and IKEA, are beginning to clean up their shipping pollution. In 2021, a group of companies pledged that by 2040 it will only contract ships using zero-carbon fuels to move freight (The Verge, 2021).

Active patent portfolio development of the most active global ship manufacturers in fuel cells

Figure 37. Active patent portfolios of the most active global ship manufacturers in fuel cells, 2005–2021.

Republic of Korea shipping manufacturers lead in the number of active patents. In contrast to road and rail, Chinese companies have no significant active patent portfolios.



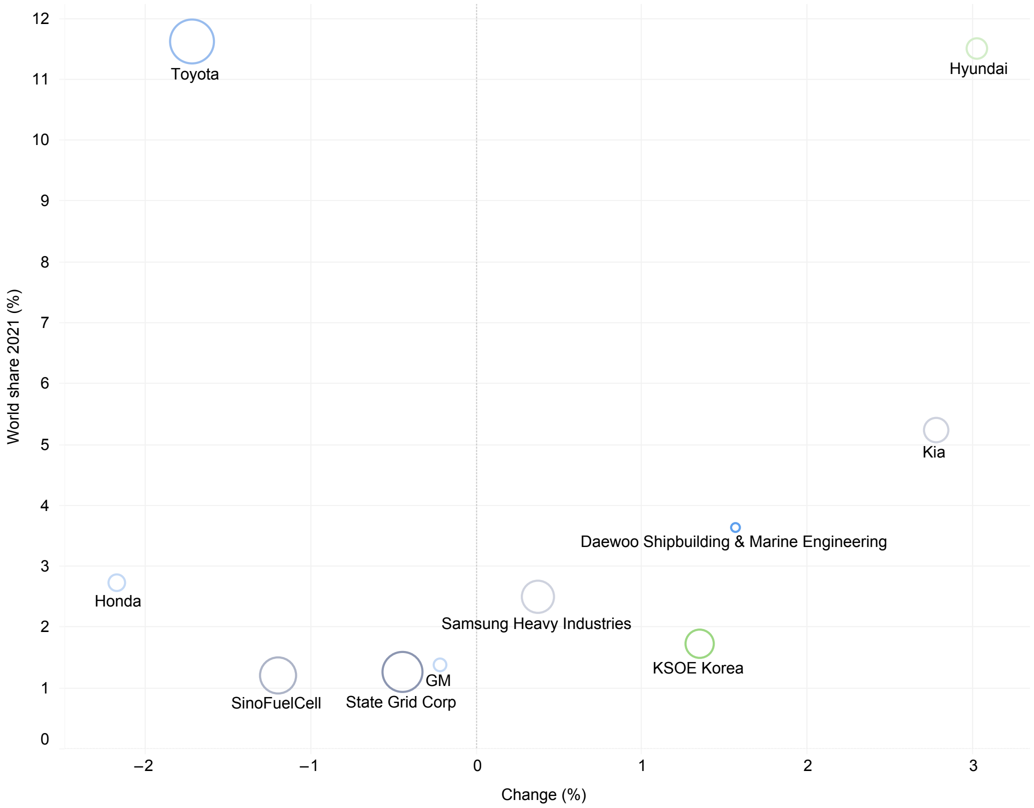
Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

The top patent applicant within the patent data set is Daewoo Shipbuilding (Figure 37), whose patent portfolio is more than twice that of the second highest patent applicant, KSOE (HKorea Shipbuilding). Interest from some of the major companies in the field is reflected in the patent data set, with Wärtsilä, MAN, and Maersk featuring as top patent applicants, yet having very small patent portfolios.

Unlike for road and rail, Chinese companies are not active in applications related to shipping and marine vehicles. China Shipbuilding is the leading player in China in terms of patent filings and has been filing more patents recently and is the only Chinese company in the top five.

Top 10 companies in shipping applications, 2015–2021

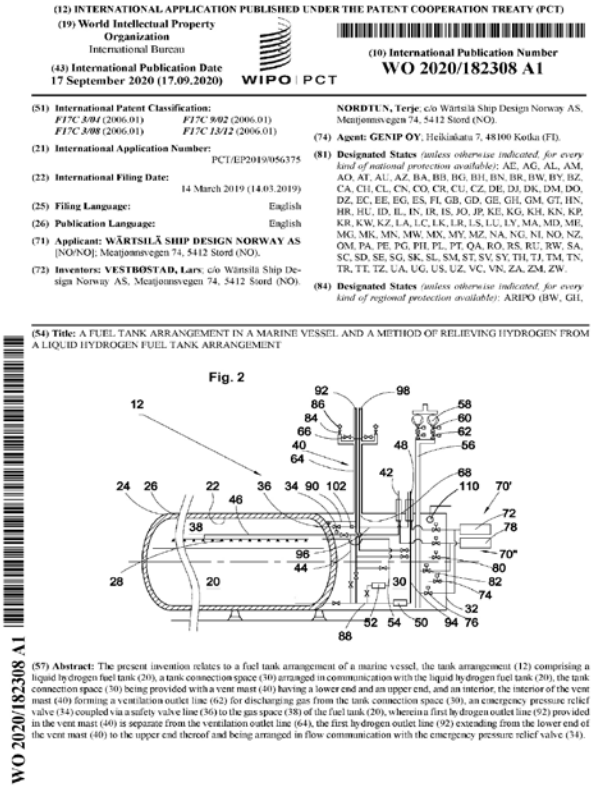
Figure 38. **World share of active patents by company compared to all players in the field versus the change in world share between 2015–2021.**
Toyota and Hyundai have the largest shares in patent applications in shipping, but whereas Toyota's active portfolio decreased between 2015–2021, Hyundai's increased during the same period.



Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

The active patent portfolios of the top patent applicants show Toyota and Hyundai have the largest world shares in the field of fuel cell shipping applications, but with differing dynamics during the period 2015–2021, when Toyota's contracted slightly while Hyundai's grew by more than 3 percent. Apart from Kia in third place, the other dynamic companies in the field are the shipping specialists Daewoo Shipbuilding, Samsung Heavy Industries and KSOE (Korea Shipbuilding).

Figure 39.1 Patent example: Wärtsilä, WO2020182308. A fuel tank arrangement in a marine vessel and a method of relieving hydrogen from a liquid tank arrangement.



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(71) **Applicant: WÄRTSILÄ SHIP DESIGN NORWAY AS** [NO/NO]; Meatjonnsvegen 74, 5412 Stord (NO).

(72) **Inventors: VESTBØSTAD, Lars**; c/o Wärtsilä Ship Design Norway AS, Meatjonnsvegen 74, 5412 Stord (NO). **NORDTUN, Terje**; c/o Wärtsilä Ship Design Norway AS, Meatjonnsvegen 74, 5412 Stord (NO).

(74) **Agent: GENIP OY**; Heikinkatu 7, 48100 Kotka (FI).

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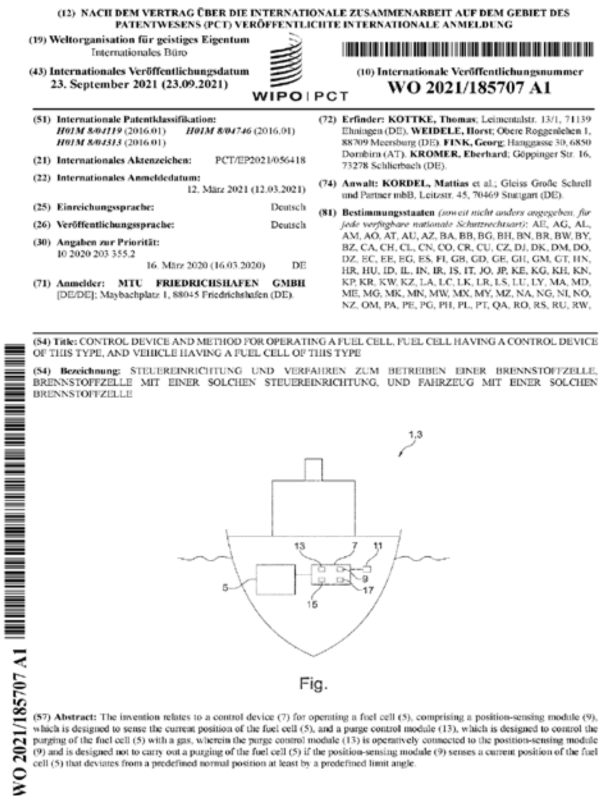
(54) **Title:** A FUEL TANK ARRANGEMENT IN A MARINE VESSEL AND A METHOD OF RELIEVING HYDROGEN FROM A LIQUID HYDROGEN FUEL TANK ARRANGEMENT

Fig. 2

(57) **Abstract:** The present invention relates to a fuel tank arrangement of a marine vessel, the tank arrangement (12) comprising a liquid hydrogen fuel tank (20), a tank connection space (30) arranged in communication with the liquid hydrogen fuel tank (20), the tank connection space (30) being provided with a vent mast (40) having a lower end and an upper end, and an interior, the interior of the vent mast (40) forming a ventilation outlet line (62) for discharging gas from the tank connection space (30), an emergency pressure relief valve (34) coupled via a safety valve line (36) to the gas space (38) of the fuel tank (20), wherein a first hydrogen outlet line (92) provided in the vent mast (40) is separate from the ventilation outlet line (64), the first hydrogen outlet line (92) extending from the lower end of the vent mast (40) to the upper end thereof and being arranged in flow communication with the emergency pressure relief valve (34).

WO 2020/182308 A1

Figure 39.2 Patent example: MTU Friedrichshafen, now Rolls-Royce Solutions, WO2021185707. Control device and method for operating a fuel cell, fuel cell having a control device of this type, and vehicle having a fuel cell of this type.



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(71) **Anmelder: MTU FRIEDRICHSHAFEN GMBH** [DE/DE]; Maybachplatz 1, 88045 Friedrichshafen (DE).

(72) **Erfinder: KOTTKE, Thomas**; Leimentalstr. 13/1, 71139 Ehningen (DE). **WEIDELE, Horst**; Obere Roggenlehen 1, 88709 Meersburg (DE). **FINK, Georg**; Hanggasse 30, 6850 Dornbirn (AT). **KROMER, Eberhard**; Göppinger Str. 16, 73278 Schlierbach (DE).

(74) **Anwalt: KORDEL, Mattias** et al.; Gleiss Große Schrell und Partner mbB, Leitzstr. 45, 70469 Stuttgart (DE).

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(54) **Title:** CONTROL DEVICE AND METHOD FOR OPERATING A FUEL CELL, FUEL CELL HAVING A CONTROL DEVICE OF THIS TYPE, AND VEHICLE HAVING A FUEL CELL OF THIS TYPE

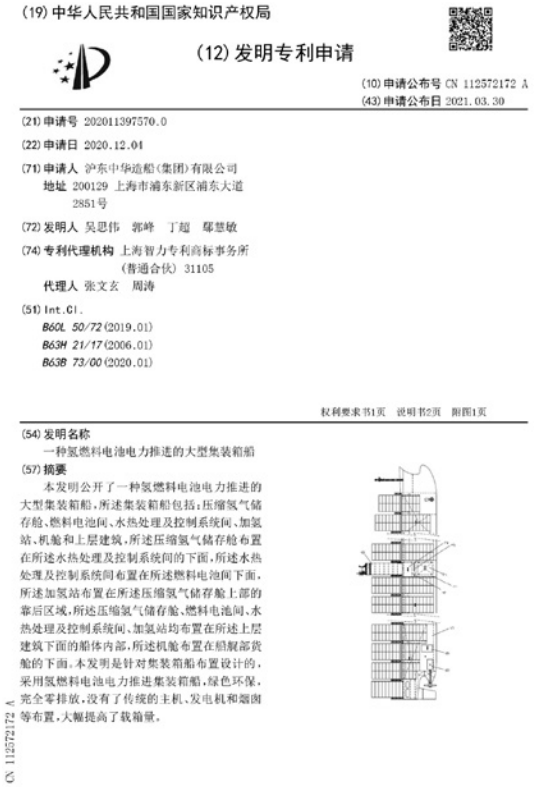
(54) **Bezeichnung:** STEUEREINRICHTUNG UND VERFAHREN ZUM BETREIBEN EINER BRENNSTOFFZELLE, BRENNSTOFFZELLE MIT EINER SOLCHEN STEUEREINRICHTUNG, UND FAHRZEUG MIT EINER SOLCHEN BRENNSTOFFZELLE

Fig.

(57) **Abstract:** The invention relates to a control device (7) for operating a fuel cell (5), comprising a position-sensing module (9), which is designed to sense the current position of the fuel cell (5), and a purge control module (13), which is designed to control the purging of the fuel cell (5) with a gas, wherein the purge control module (13) is operatively connected to the position-sensing module (9) and is designed not to carry out a purging of the fuel cell (5) if the position-sensing module (9) senses a current position of the fuel cell (5) that deviates from a predefined normal position at least by a predefined limit angle.

WO 2021/185707 A1

Figure 39.3 Patent example: China Shipbuilding Group, Hudong Zhonghua Shipbuilding Group, CN112572172. Hydrogen fuel cell electric propulsion for a large container ship.



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(71) 申请人 沪东中华造船(集团)有限公司
地址 200129 上海市浦东新区浦东大道
2851号

(72) 发明人 吴思伟 郭峰 丁超 鄢慧敏

(74) 专利代理机构 上海智力专利商标事务所
(普通合伙) 31105
代理人 张文玄 周涛

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权利要求书1页 说明书2页 附图1页

(54) 发明名称
一种氢燃料电池电力推进的大型集装箱船

(57) 摘要
本发明公开了一种氢燃料电池电力推进的大型集装箱船，所述集装箱船包括：压缩氢气储存舱、燃料电池间、水热处理及控制系统间、加氢站、机舱和上层建筑，所述压缩氢气储存舱布置在所述水热处理及控制系统间的下面，所述水热处理及控制系统间布置在所述燃料电池间下面，所述加氢站布置在所述压缩氢气储存舱上部的靠后区域，所述压缩氢气储存舱、燃料电池间、水热处理及控制系统间、加氢站均布置在所述上层建筑下面的船体内部，所述机舱布置在艉部货舱的下面。本发明是针对集装箱船布置设计的，采用氢燃料电池电力推进集装箱船，绿色环保，完全零排放，没有了传统的主机、发电机和烟囱等布置，大幅提高了载箱量。

CN 112572172 A

Applicants	HUDONG ZHONGHUA SHIPBUILDING GROUP CO LTD – 沪东中华造船（集团）有限公司; HUDONG-ZHONGHUA SHIPBUILDING (GROUP) CO., LTD.
Inventors	WU SIWEI; GUO FENG; DING CHAO; YAN HUIMIN – 吴思伟; 郭峰; 丁超; 鄢慧敏; WU SIWEI; GUO FENG; DING CHAO; YAN HUIMIN

Hydrogen fuel cell electric propulsion large container ship

Abstract

The invention discloses a hydrogen fuel cell electric propulsion large container ship. The ship comprises a compressed hydrogen storage cabin, a fuel cell room, a hydro-thermal treatment and control system room, a hydrogen refueling station, a cabin and a superstructure, wherein the compressed hydrogen storage cabin is arranged below the hydro-thermal treatment and control system room, and the hydro-thermal treatment and control system room is connected with the hydrogen refueling station; the hydro-thermal treatment and control system room is arranged below the fuel cell room, the hydrogen refueling station is arranged in the rear area of the upper portion of the compressed hydrogen storage cabin, and the compressed hydrogen storage cabin, the fuel cell room, the hydro-thermal treatment and control system room and the hydrogen refueling station are all arranged in a ship body below the superstructure; and the cabin is arranged below the stern cargo hold. The hydrogen fuel cell electric propulsion container ship is designed for container ship arrangement, the hydrogen fuel cell electric propulsion container ship is adopted, environmental protection is achieved, zero emission is achieved completely, traditional arrangement of a main engine, a generator, a chimney and the like is avoided, and the container carrying capacity is greatly improved.

The top two companies in shipping, as in other applications, are Toyota and Hyundai (Table 5). However, it is noteworthy that Toyota's lead in shipping is not so pronounced as it is in the other applications, but instead on par with Hyundai. Also, the special requirements for shipping applications are reflected in the composition of the top 20 companies. Daewoo Shipbuilding, Samsung Heavy Industries, KSOE (Korea Shipbuilding), China Shipbuilding Group and Naval Group are all shipping specialists that have moved into fuel cell technologies and built significant portfolios.

Top companies in transport in shipping applications, active patent portfolio and filing development

Table 5. **Active patent portfolios of the leading 20 players in fuel cells in shipping (left part of table) compared to recent patent filing activity (all patents, active and inactive, right part of table).**
Toyota and Hyundai lead in active portfolios in shipping applications, with double the number of patents of the third-placed company, Kia.

Company	Active patent portfolios	2000	2005	2010	2015	2019	2021	2015	2016	2017	2018	2019
Toyota		17	88	553	481	564	603	14	42	30	49	18
Hyundai		1	3	88	306	526	597	70	66	33	46	38
Kia		0	0	24	89	197	272	20	24	33	45	38
Daewoo Shipbuilding & Marine Engineering		0	1	8	75	159	189	48	39	23	25	15
Honda		5	34	149	177	154	142	2	13	1	9	4
Samsung Heavy Industries		0	0	2	77	111	130	21	14	8	17	3
KSOE Korea		0	1	1	14	92	90	61	14	3	9	8
GM		3	14	32	58	78	72	7	4	8	5	1
State Grid Corp		0	11	62	62	63	66	0	1	0	0	0
SinoFuelCell		0	22	112	87	63	63	0	0	0	0	0
Bosch		2	8	10	16	22	55	4	1	3	3	21
Thyssenkrupp		2	11	20	29	43	47	5	4	4	1	2
Denso		4	74	88	86	48	44	1	1	0	2	1
China Shipbuilding Group		0	0	0	2	15	44	1	1	3	2	10
Boeing		0	1	12	29	41	39	5	2	4	2	0
VW Group		1	8	12	23	29	36	1	2	2	4	5
Airbus Group		0	4	15	29	24	30	1	0	0	3	4
Siemens Energy		2	11	14	26	30	28	2	3	1	3	1
GE		4	5	18	27	29	28	4	6	0	2	1
Naval Group		0	10	19	26	27	27	0	0	0	4	3

Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

Fuel cell application: aviation and above-ground vehicles

The commercial aviation sector is facing an ongoing challenge of reconciling increasingly stringent environmental regulations and emissions commitments with an anticipated growth in passenger demand. Momentum in hydrogen for aviation applications has been re-energized after many years dormant due to technical challenges, the most fundamental of which for hydrogen fuel cell aircraft is weight. Fuel cells are therefore often only considered for on-board electrification rather than propulsion. The same situation applies to spacecraft. NASA has in the past used fuel cells for electrification on-board spacecraft, but not for propulsion. NASA has, however, used hydrogen directly to propel rockets without the need to convert to electrical power (NASA, 2021a).

In 2020, Airbus took the first major step in this direction, releasing an ambitious plan for developing novel hydrogen aircraft concepts, called ZEROe, for carrying up to 200 passengers and a range of 3,700 km, with the goal of having a commercial aircraft available by 2035 (Airbus, 2020). Airbus said it selected the A380, the world's largest passenger plane, because it had room enough to store the necessary liquid hydrogen tanks and other equipment and could fly in 2026. The manufacturer is working with engine-maker CFM International, a joint venture between GE and France's Safran (CNBC, 2022).

Airbus did, however, also report to the European Union that most airliners will continue to rely on traditional jet engines up until at least 2050, with zero-emission hydrogen planes likely to be principally confined to regional and shorter-range aircraft from 2035 (Reuters, 2021b).

In addition, Boeing recently partnered with Australia's Commonwealth Scientific and Industrial Research Organization to publish a roadmap for hydrogen in the aviation industry. This considered what are the opportunities for hydrogen use in aircraft, as well as airport applications, and ruled out hydrogen being used on a significant scale before 2050 (Reuters, 2021b; CSIRO, 2021). In 2021, GE Aviation and Safran launched an innovation development program for sustainable engines, extending their partnership until 2050 (Fuel Cell Works, 2021b).

Chinese companies are not similarly active in aviation as they are in road or rail, or in niche areas such as drones. Some suppliers address the field, but none of the larger aircraft players is among the top ranks.

Several smaller companies, such as Universal Hydrogen and ZeroAvia, are working on hydrogen aircraft solutions for short-distance flights. Backed by investors that include the venture capital arms of Airbus, Toyota and JetBlue, Universal Hydrogen recently raised funds to ramp up industrially and accelerate toward a first test flight in 2022 (Businesswire, 2021). Its aim is to speed up the introduction of hydrogen for smaller regional airplanes by 2025, replacing turboprop systems with fuel cells fed by modular hydrogen capsules. Hydrogen aviation company ZeroAvia has announced its biggest zero-emissions hydrogen aircraft yet – a 76-seat airliner to be built with Alaska Airlines it is hoping to fly in 2023 –, as well as a first commercial hydrogen-powered flight between London and Rotterdam in 2024 (New Atlas, 2021).

Experts say the high cost of hydrogen, the challenges of storing and super-cooling the gas and building a reliable and widespread supply system, as well as certification, must all be addressed. However, in view of the fact that bringing a new airplane to market can take up to between five and seven years of design, development and production, the CEO of Universal Hydrogen has said that decisions need to made by the late 2020s in order to enter the market by mid-2030s (Reuters, 2022).

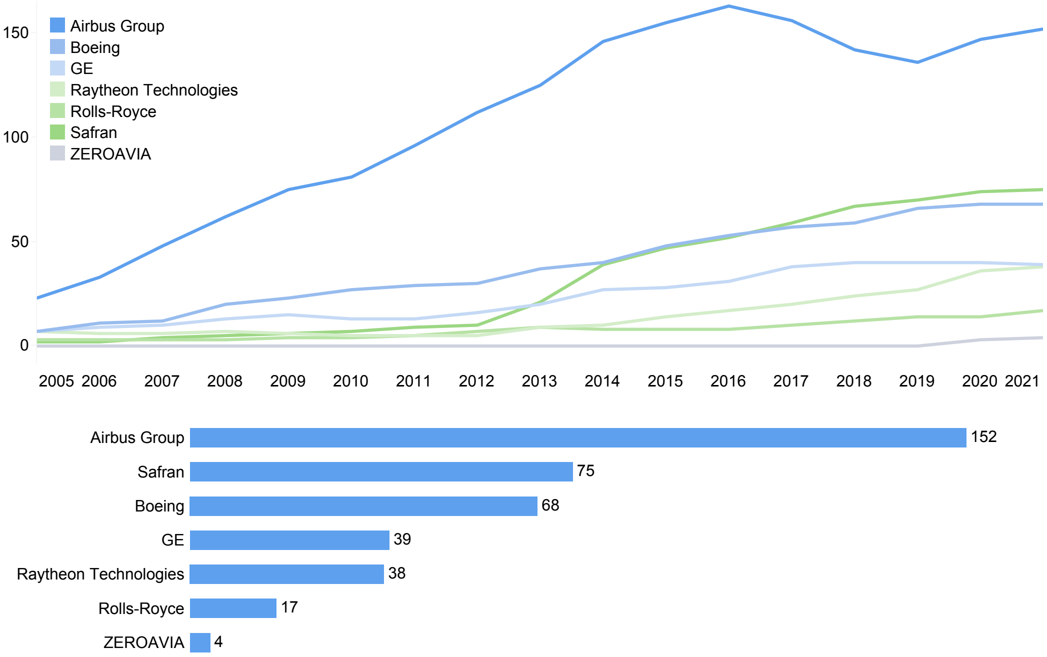
Airbus is leading the field, with a slight reduction in its patent portfolio in 2016, but having filed increasing numbers of applications over all in the last few years. Boeing, Safran, Ratheon, GE, Rolls-Royce and small newcomers, such as Zeroavia or H2Fly, are behind Airbus in the ranking, but following a generally upward trend (Figure 40).

While the direct use of hydrogen in commercial aviation is not expected to become commercially viable until the mid-2030s, or later, hydrogen-based synthetic kerosene used as a drop-in fuel for existing aircraft could come on the market by 2030. A first flight using synthetic kerosene was carried out by KLM in the Netherlands in February 2021 (KLM, 2021). According to the IEA Net Zero Emissions by 2050 Scenario, synthetic kerosene will meet more than 1.6 percent of aviation fuel demand by 2030 (IEA, 2021b).

Besides general commercial aviation, there are also quite a few patents describing fuel cells in other above-ground technologies. Drones and personal flying cars (PFVs), vertical take-off and landing (VTOL) craft, high-altitude platforms (HAPs) and satellites have already been described and claimed in patents. Most of these applications are as yet market niches, but expected to grow in the coming years. In the case of satellites, we have seen that NASA used fuel cells in the 1960s. As flying cars have been investigated and patented to a quite remarkable degree, it is little wonder that fuel cells have already been used, at least optionally, by car manufacturers.

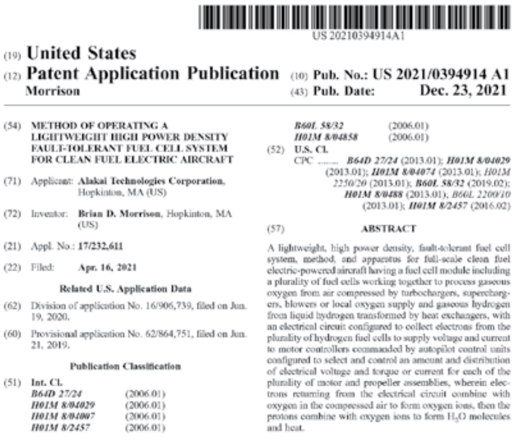
Active patent portfolio development of the most active aviation companies

Figure 40. Active patent portfolios of the most active aviation companies, 2005–2021.
The leader, Airbus Group, has almost double the active patent portfolio of the second player, Safran.



Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

Figure 41. Example: Metro Aviation (which has acquired Applicant Alakai Technologies), WO2020257646. Lightweight high power density fault-tolerant fuel cell system. Method and apparatus for clean fuel electric aircraft.



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(19) **United States**
(12) **Patent Application Publication**
Morrison

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(43) **Pub. Date: Dec. 23, 2021**

(54) **METHOD OF OPERATING A LIGHTWEIGHT HIGH POWER DENSITY FAULT-TOLERANT FUEL CELL SYSTEM FOR CLEAN FUEL ELECTRIC AIRCRAFT**

(71) Applicant: **Alakai Technologies Corporation**, Hopkinton, MA (US)

(72) Inventor: **Brian D. Morrison**, Hopkinton, MA (US)

(21) Appl. No.: **17/232,611**

(22) Filed: **Apr. 16, 2021**

Related U.S. Application Data

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(60) Provisional application No. 62/864,751, filed on Jun. 21, 2019.

Publication Classification

(51) **Int. Cl.**

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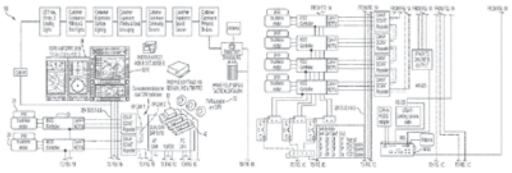
H01M 8/04858	(2006.01)

(52) **U.S. Cl.**
CPC ***B64D 27/24*** (2013.01); ***H01M 8/04029*** (2013.01); ***H01M 8/04074*** (2013.01); *H01M 2250/20* (2013.01); ***B60L 58/32*** (2019.02); ***H01M 8/0488*** (2013.01); *B60L 2200/10* (2013.01); ***H01M 8/2457*** (2016.02)

(57) **ABSTRACT**

A lightweight, high power density, fault-tolerant fuel cell system, method, and apparatus for full-scale clean fuel electric-powered aircraft having a fuel cell module including a plurality of fuel cells working together to process gaseous oxygen from air compressed by turbochargers, superchargers, blowers or local oxygen supply and gaseous hydrogen from liquid hydrogen transformed by heat exchangers, with an electrical circuit configured to collect electrons from the plurality of hydrogen fuel cells to supply voltage and current to motor controllers commanded by autopilot control units configured to select and control an amount and distribution of electrical voltage and torque or current for each of the plurality of motor and propeller assemblies, wherein electrons returning from the electrical circuit combine with oxygen in the compressed air to form oxygen ions, then the protons combine with oxygen ions to form H_2O molecules and heat.



The top players in the field are Hyundai and Toyota, each with an active patent portfolio of more than 500 patent families in 2021. The top 10 also contains many aviation specialists such as Airbus, Safran, Boeing and Raytheon Technologies (Table 6). However, it should be emphasized that hardly any of the players in the top 20 have any significant momentum in patent development. Apart from Hyundai and Kia, almost all competitors are stagnating, the exceptions being Safran, Raytheon, VW Group and Bosch, though all four are still at a comparatively low patent level. Interestingly, there is quite a lot of new activity visible at Airbus, but only since about 2019, which is in line with their proclaimed strategy.

Top 20 companies in transport in aviation applications, active patent portfolio and filing development

Table 6. **Active patent portfolios of the leading 20 players in fuel cells in aviation (left part of table) compared to recent patent filing activity (all patents, active and inactive, right part of table).**
As seen in other areas, Hyundai and Toyota again lead in active patent portfolios in aviation.

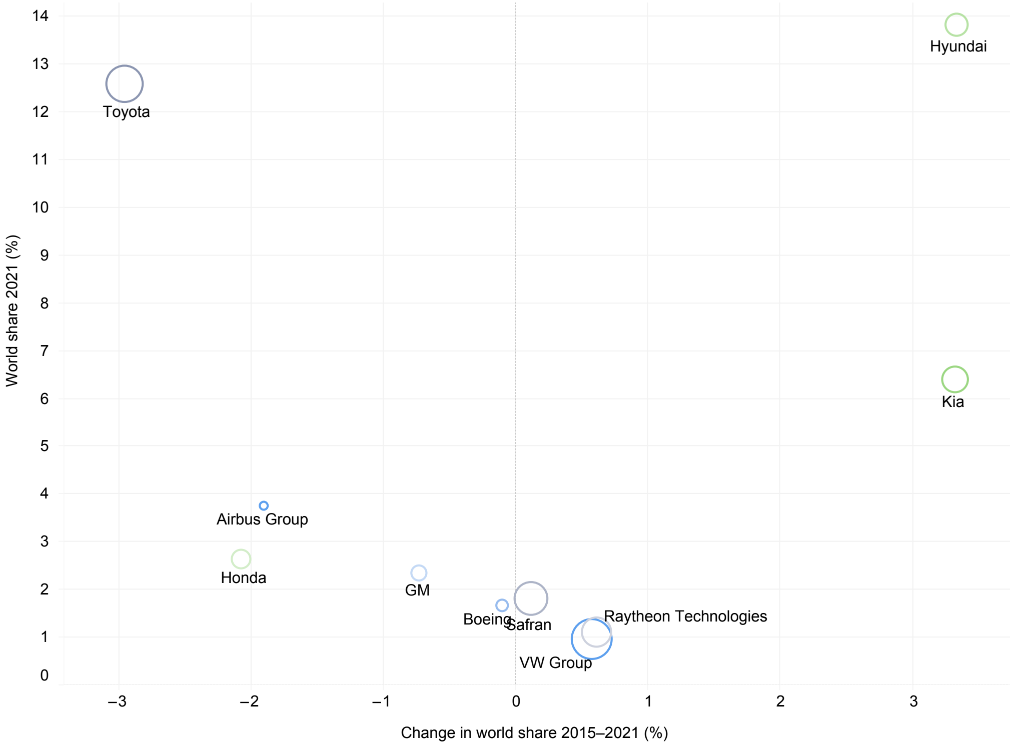
Company	Active patent portfolios	2000	2005	2010	2015	2019	2021	2015	2016	2017	2018	2019
Hyundai		1	1	78	289	500	570	68	62	33	45	37
Toyota		4	76	527	428	477	519	11	28	23	43	23
Kia		0	0	24	85	190	264	20	21	33	45	37
Airbus Group		4	23	82	156	137	155	5	6	6	10	21
Honda		0	4	96	130	115	109	1	10	2	9	3
GM		0	18	42	85	102	97	7	4	10	3	6
Safran		0	2	7	47	70	75	9	12	8	5	6
Boeing		2	7	27	49	67	69	6	5	6	4	1
Raytheon Technologies		9	7	5	14	28	46	3	3	4	5	8
VW Group		0	6	6	11	26	40	6	3	5	6	9
GE		0	7	13	28	40	39	9	7	5	3	1
Bosch		0	5	9	10	18	37	3	3	2	4	13
Shanghai Hydrogen		0	0	0	4	46	30	8	11	30	0	0
Denso		0	2	8	17	30	29	5	4	2	4	1
Nissan		2	22	31	21	28	28	1	5	6	2	0
Intelligent Energy		0	2	22	23	25	22	3	0	1	0	1
Ford		0	0	2	6	17	20	0	4	5	2	3
StradVision		0	0	0	0	2	20	0	0	0	2	11
Textron		1	2	2	2	11	18	0	1	7	6	7
Rolls-Royce		0	3	4	8	14	18	2	2	2	1	5

Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

The stagnating patent development of most players dominates the competitive environment. Hyundai and Kia have advanced an already exceptional competitive position with increases in their world shares above three percentage points in recent years at the expense of almost all other players (Figure 42). Since we measure share development over a five-year period, Airbus continues to be on the left, decreasing side. Their recent activity will have therefore only alter the world share dynamic in a future analysis, if recent activity results in more solid trend.

Top 10 companies in aviation applications, world shares and change in world shares, 2015–2021

Figure 42. **World share of active patents by company in the field of aviation compared to all players in the field versus the change of this world share between 2015–2021.**
Although Hyundai and Toyota have world leading shares, Hyundai's has increased in the last few years whereas Toyota’s has decreased.



Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

Fuel cell application: rail and track vehicles

In rail and track vehicles, new applications are gaining in popularity. Alstom led the way in Europe, completing a successful 18-month trial of two trains in Germany in 2020 (Alstom, 2020a). In 2021, Alstom announced further plans to introduce fuel cell trains in Austria and Italy (CleanTechnica, 2021). This has resulted in orders for at least 41 units in Germany and six in Italy to be put into service between 2021 and 2022 (Alstom, 2020b, 2020c).

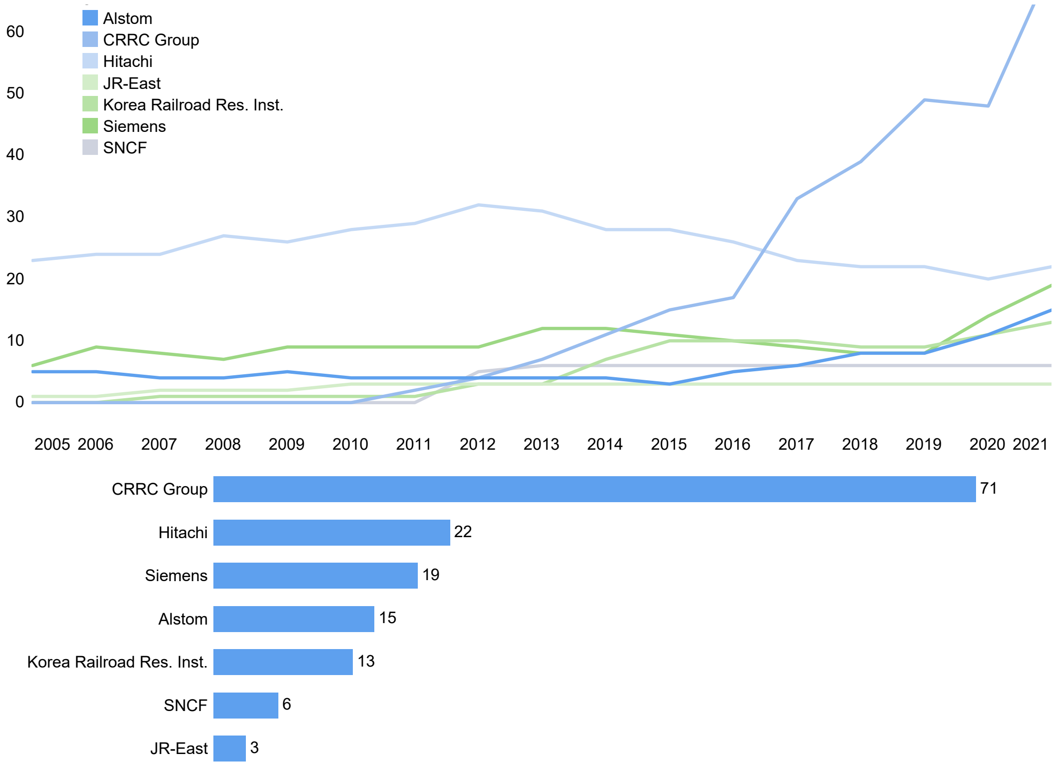
Other European companies in France (SNCF, 2021), Germany (Siemens Mobility, 2021), Spain (CAF, 2021) and the United Kingdom (Railway Technology, 2021) have either started working with Alstom or are developing and testing their own fuel cell train models, with the objective of replacing diesel trains on non-electrified routes. In Germany, Siemens Mobility and Deutsche Bahn have started developing hydrogen-powered fuel cell trains and a filling station which will be trialed in 2024 (Reuters, 2020b). Scotland set a 2035 decarbonization goal for its passenger rail system in 2021 and started a fuel cell train initiative spearheaded by the recently established firm Arcola Energy (CleanTechnica, 2021).

Outside Europe, countries such as China, Canada, Japan, the Republic of Korea and the U.S. are also showing interest in hydrogen fuel cell trains. In addition to passenger trains, hydrogen trams and line-haul and switching locomotives are in various stages of development and deployment.

Active patent portfolios of leading railroad and track-side active players, claiming rail or track applications in relation to fuel cells

Figure 43. Active patent portfolios of leading railroad and track-side active players, claiming rail or track applications in relation to fuel cells, 2005–2021.

Chinese players are growing their portfolios, while most others have either a fairly stable or even a shrinking portfolio.



Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

Patents describing optional rail or track-side applications are commonly found for many automotive players, since track and road applications can overlap tramway applications or applications in industrial zones. Therefore, without being active in the railroad applications market, car manufacturers are nevertheless among the overall leading players in terms of patents in the field.

Hydrogen trains in the main are expected to replace diesel on railway lines uneconomical to electrify due to relatively low utilization, constituting 2 percent of rail energy consumption by 2030 according to the IEA Net Zero Emissions by 2050 Scenario (IEA, 2021b).

Top 20 player analysis shows no exceptionally strong players, unlike the other applications analyzed (Table 7). Toyota is in the lead, followed by four players who are par with each other, each with an active patent portfolio of around 100 patent families in 2021. The aforementioned specialist CRRC Group is in second place, but most players are from the automotive industry. It can also be seen that a lack of dynamics in applications in general also applies to most of the top 20 players. Only a very few players, such as Toyota, VW Group or CRRC, have significantly expanding patent portfolios. Several other train manufacturers, such as Siemens and Alstom, have also increased the size of their patent portfolios, but nevertheless they remain small overall.

Top 20 companies in transport in rail applications, active patent portfolio and filing development

Table 7. Active patent portfolios of the leading 20 players in fuel cells in rail and track vehicles (left part of table) compared to recent patent filing activity (all patents, active and inactive, right part of table).

Apart from CRRC Group, most of the leading players are from the automotive industry.

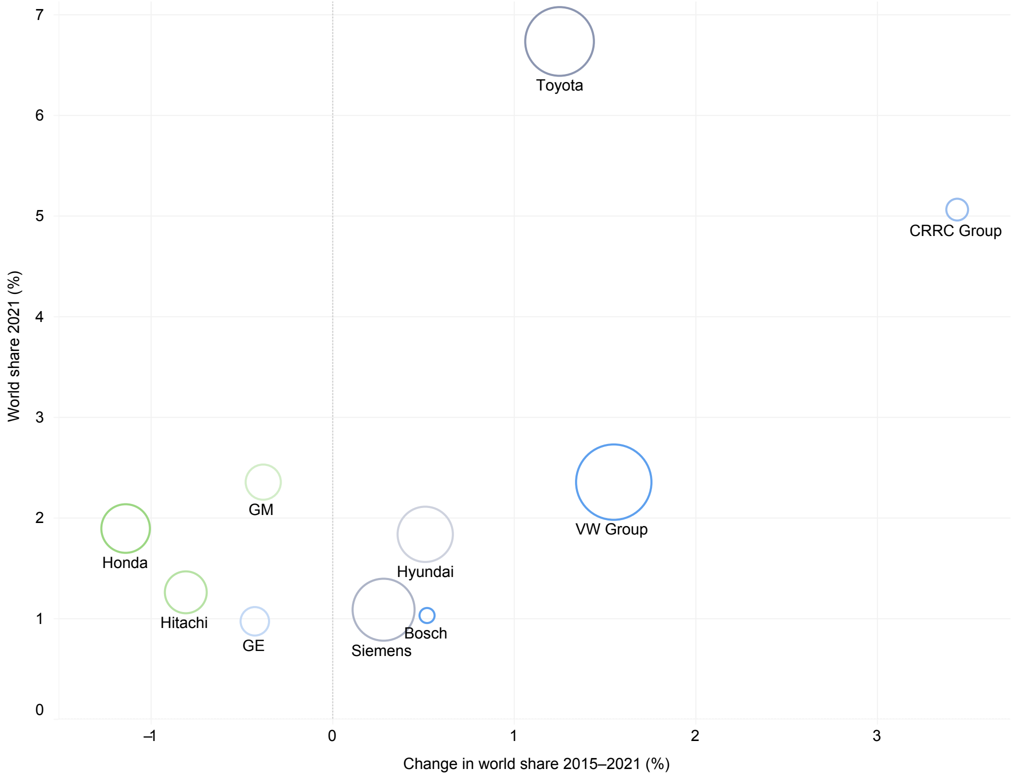
Company	Active patent portfolios	2000	2005	2010	2015	2019	2021	2015	2016	2017	2018	2019
Toyota		3	19	80	74	94	117	7	7	9	20	8
CRRC Group		0	0	1	22	61	88	9	17	16	8	10
GM		1	24	28	37	41	41	4	1	6	2	3
VW Group		2	3	5	11	31	41	4	8	9	3	8
Honda		3	16	31	41	37	33	4	2	1	2	0
Hyundai		3	2	5	18	28	32	1	2	0	1	4
Hitachi		18	23	28	28	22	22	0	0	0	1	0
Siemens		4	6	9	11	8	19	0	0	0	8	6
Bosch		3	5	8	7	11	18	1	1	3	2	5
GE		1	7	17	19	18	17	1	1	0	4	0
Ford		0	2	4	7	18	17	2	4	2	3	0
State Power Investment Group		0	0	0	0	12	16	0	0	0	12	0
Alstom		3	5	4	3	8	15	3	1	0	3	2
Kia		0	0	2	5	10	15	0	2	0	1	4
Murata Manufacturing		0	1	1	10	14	14	2	1	2	0	0
Toray		1	9	13	16	14	13	0	0	0	0	0
Toshiba		8	7	12	11	11	12	0	2	1	0	2
Volvo		0	2	5	8	9	12	1	1	2	2	0
Nissan Motor		1	17	17	14	14	11	0	0	2	1	0
Daimler Truck		0	0	1	4	8	11	1	1	2	2	0

Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

The competitive environment shows Toyota has been able to extend its lead significantly in recent years. The aforementioned CRRC Group and VW Group were likewise able to increase their world shares, but to a lesser degree than Toyota. Due to the general lack of a dynamic development in applications, small absolute increases in patent portfolios result in appreciable increases in world shares when compared to the static competition.

Top 10 companies in rail applications, 2015–2021

Figure 44. World share of active patents by company compared to all players in the field of rail in 2021 and change to this world share between 2015–2021.
Toyota again leads in the share of active patent portfolio and has increased its share in the last few years.



Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

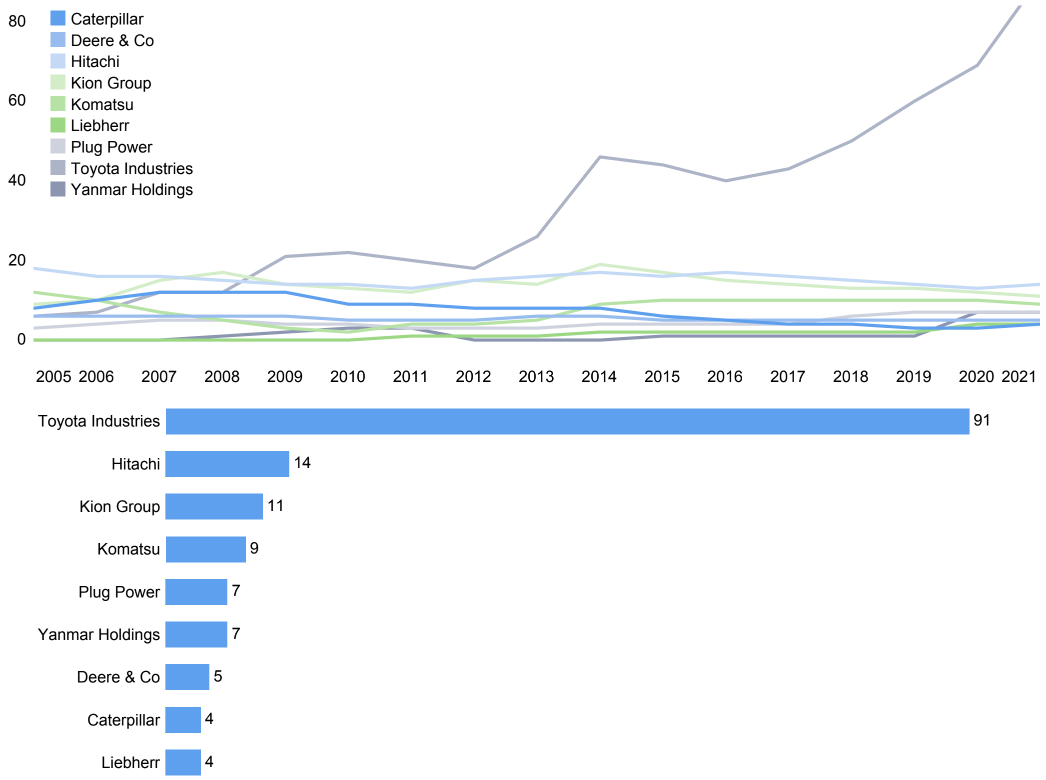
Fuel cell application: special vehicles

Special vehicles is a group of vehicles designed for special applications or specific tasks. Typically, they are commercial vehicles produced in smaller numbers, often for defined and closed working environments, such as airports, harbors or construction sites. Furthermore, many of the smaller players and SMEs are successfully addressing these niche markets, paving the way for newer technologies such as fuel cells. Furthermore, special vehicles are often the ideal candidates for SME partnerships comprising fuel cell producers, integrators and special vehicles manufacturers. Examples of such players are Gaussin.com (fuel cell airport tugs) together with Plug Power; Nuvera.com (part of Hyster-Yale) with their integrator Simply Hydrogen in China; and Infintium (a U.S. company that in March 2021 started building a fuel cell fork-lift factory in China) and GlobeFuelCell.com, a spin-off from Mercedes-Benz. It is especially the case in the field of special vehicles that many of the small players do not have many of their own patents, but instead sometimes license patents from universities or integrate parts from other fuel cell suppliers. Their footprint in the patent landscape is therefore rather small, as yet.

At the same time, large manufacturers like Kion, Caterpillar, Yanmar, Komatsu, Hitachi and Toyota Industries are similarly active in the field – an indication of its obvious large market potential in the future. Altogether, we expect there to be a noticeable growth in patent activity in this field over the years to come, in line with an expected roll-out of an increasing number of fuel cell special vehicles onto the market.

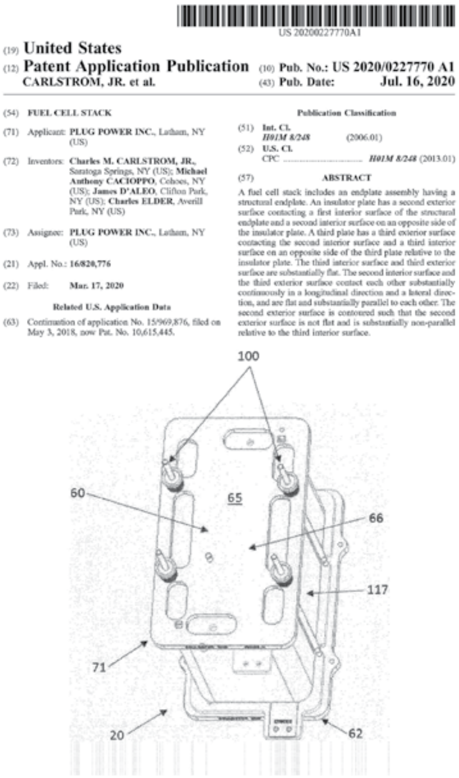
Active patent portfolio development of most active players in special vehicles

Figure 45. Active patent portfolios of the most active players in special vehicles, 2005–2021.
Several large manufactures, which do not feature in other application areas, are the players with the most active patent portfolios in special vehicles.



Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

Figure 46.1. Patent example: Plug Power, also a partner of Gaussin, WO2019213351. Fuel cell tank.



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(54) **FUEL CELL STACK**

(71) Applicant: **PLUG POWER INC.**, Latham, NY (US)

(72) Inventors: **Charles M. CARLSTROM, JR.**, Saratoga Springs, NY (US); **Michael Anthony CACIOPPO**, Cohoes, NY (US); **James D'ALEO**, Clifton Park, NY (US); **Charles ELDER**, Averill Park, NY (US)

(73) Assignee: **PLUG POWER INC.**, Latham, NY (US)

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Publication Classification

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H01M 8/248 (2006.01)
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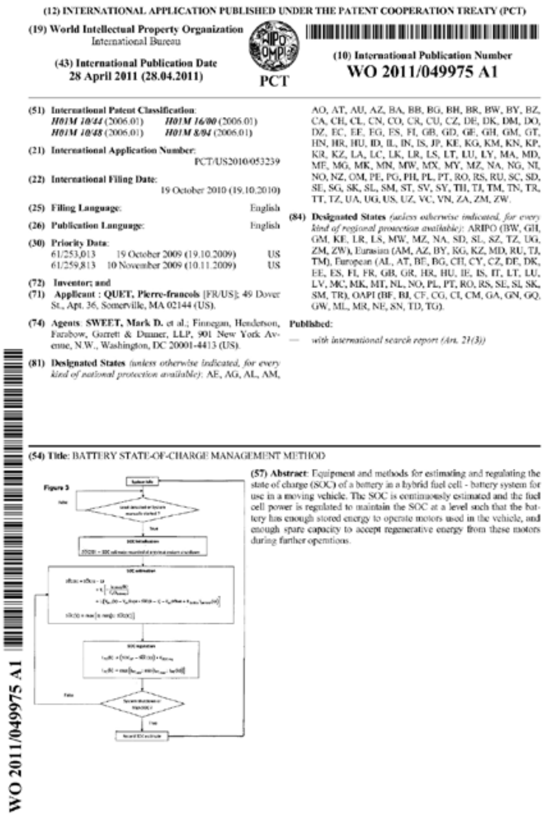
CPC *H01M 8/248* (2013.01)

(57) **ABSTRACT**

A fuel cell stack includes an endplate assembly having a structural endplate. An insulator plate has a second exterior surface contacting a first interior surface of the structural endplate and a second interior surface on an opposite side of the insulator plate. A third plate has a third exterior surface contacting the second interior surface and a third interior surface on an opposite side of the third plate relative to the insulator plate. The third interior surface and third exterior surface are substantially flat. The second interior surface and the third exterior surface contact each other substantially continuously in a longitudinal direction and a lateral direction, and are flat and substantially parallel to each other. The second exterior surface is contoured such that the second exterior surface is not flat and is substantially non-parallel relative to the third interior surface.

Figure 46.2. Patent example: Nuvera (partner of Simply Hydrogen, Shanghai), WO2011049975. Battery state-of-charge management method.



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(72) **Inventor; and**
(71) **Applicant : QUET, Pierre-francois** [FR/US]; 49 Dover St., Apt. 36, Somerville, MA 02144 (US).

(74) **Agents**: **SWEET, Mark D.** et al.; Finnegan, Henderson, Farabow, Garrett & Dunner, LLP, 901 New York Avenue, N.W., Washington, DC 20001-4413 (US).

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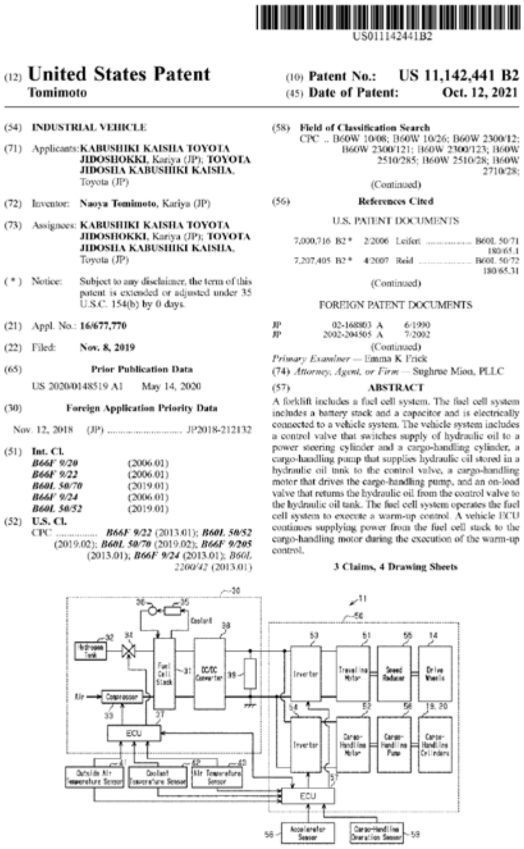
(54) **Title**: BATTERY STATE-OF-CHARGE MANAGEMENT METHOD

(57) **Abstract**: Equipment and methods for estimating and regulating the state of charge (SOC) of a battery in a hybrid fuel cell - battery system for use in a moving vehicle. The SOC is continuously estimated and the fuel cell power is regulated to maintain the SOC at a level such that the battery has enough stored energy to operate motors used in the vehicle, and enough spare capacity to accept regenerative energy from these motors during further operations.

WO 2011/049975 A1

Figure 46.3. Patent example: Toyota, US 11142441. Industrial vehicle.



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Tomimoto

(10) **Patent No.: US 11,142,441 B2**
(45) **Date of Patent: Oct. 12, 2021**

(54) **INDUSTRIAL VEHICLE**

(71) Applicants: **KABUSHIKI KAISHA TOYOTA JIDOSHOKKI**, Kariya (JP); **TOYOTA JIDOSHA KABUSHIKI KAISHA**, Toyota (JP)

(72) Inventor: **Naoya Tomimoto**, Kariya (JP)

(73) Assignees: **KABUSHIKI KAISHA TOYOTA JIDOSHOKKI**, Kariya (JP); **TOYOTA JIDOSHA KABUSHIKI KAISHA**, Toyota (JP)

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(22) Filed: **Nov. 8, 2019**

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B66F 9/22 (2006.01)
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(58) **Field of Classification Search**
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(Continued)

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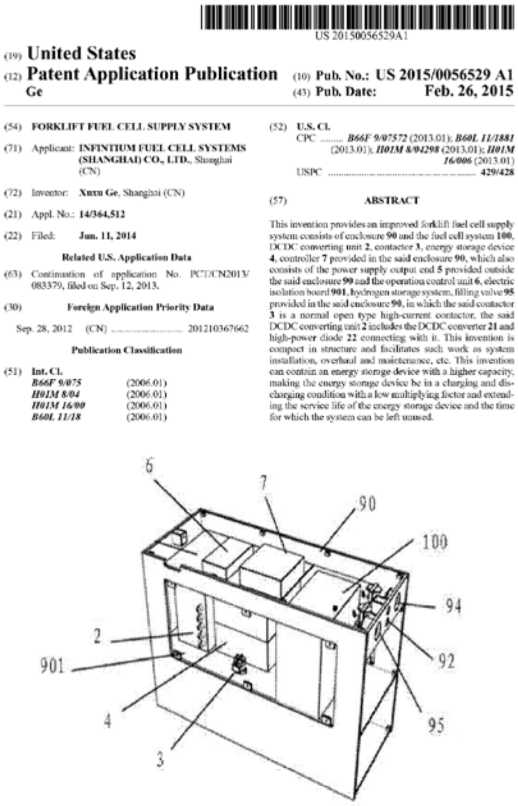
Primary Examiner — Emma K Frick
(74) *Attorney, Agent, or Firm* — Sughrue Mion, PLLC

(57) **ABSTRACT**

A forklift includes a fuel cell system. The fuel cell system includes a battery stack and a capacitor and is electrically connected to a vehicle system. The vehicle system includes a control valve that switches supply of hydraulic oil to a power steering cylinder and a cargo-handling cylinder, a cargo-handling pump that supplies hydraulic oil stored in a hydraulic oil tank to the control valve, a cargo-handling motor that drives the cargo-handling pump, and an on-load valve that returns the hydraulic oil from the control valve to the hydraulic oil tank. The fuel cell system operates the fuel cell system to execute a warm-up control. A vehicle ECU continues supplying power from the fuel cell stack to the cargo-handling motor during the execution of the warm-up control.

3 Claims, 4 Drawing Sheets

Figure 46.4. Patent example: Infintium, US 20150056529. Forklift fuel cell supply system.



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(43) **Pub. Date: Feb. 26, 2015**

(54) **FORKLIFT FUEL CELL SUPPLY SYSTEM**

(71) Applicant: **INFINTIUM FUEL CELL SYSTEMS (SHANGHAI) CO., LTD.**, Shanghai (CN)

(72) Inventor: **Xuxu Ge**, Shanghai (CN)

(21) Appl. No.: **14/364,512**

(22) Filed: **Jun. 11, 2014**

Related U.S. Application Data

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B60L 11/18	(2006.01)

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USPC **429/428**

(57) **ABSTRACT**

This invention provides an improved forklift fuel cell supply system consists of enclosure **90** and the fuel cell system **100**, DCDC converting unit **2**, contacter **3**, energy storage device **4**, controller **7** provided in the said enclosure **90**, which also consists of the power supply output end **5** provided outside the said enclosure **90** and the operation control unit **6**, electric isolation board **901**, hydrogen storage system, filling valve **95** provided in the said enclosure **90**, in which the said contactor **3** is a normal open type high-current contactor, the said DCDC converting unit **2** includes the DCDC converter **21** and high-power diode **22** connecting with it. This invention is compact in structure and facilitates such work as system installation, overhaul and maintenance, etc. This invention can contain an energy storage device with a higher capacity, making the energy storage device be in a charging and discharging condition with a low multiplying factor and extending the service life of the energy storage device and the time for which the system can be left unused.

The top 20 players are – as is the case for the other transportation application areas – once again led by Toyota (Table 8). Most players in the field have a rather small patent portfolio due to the specialized nature of the technology. The active patent portfolios of the two top companies, Toyota and Toyota Industries, exceed in size the cumulated patent portfolios of the next 10 players. Apart from automotive companies, some specialist players with small but very dynamic portfolios, such as Michelin, are among the top five. Other specialist players, namely Bloom Energy, Kion Group and Komatsu, are similarly small in size, but in their case not very dynamic, with the exception of Carrier, which has increased an as yet small portfolio remarkably. It is also worth noting that some ship manufacturers, such as Daewoo, are active in special (harbor) vehicles, too.

Top 20 companies in transport in special vehicles applications, active patent portfolio and filing development

Table 8. Active patent portfolios of the leading 20 players in fuel cells in special vehicles (left part of table) compared to recent patent filing activity (all patents, active and inactive, right part of table).

In contrast to other application areas, patent portfolios are smaller in special vehicles.

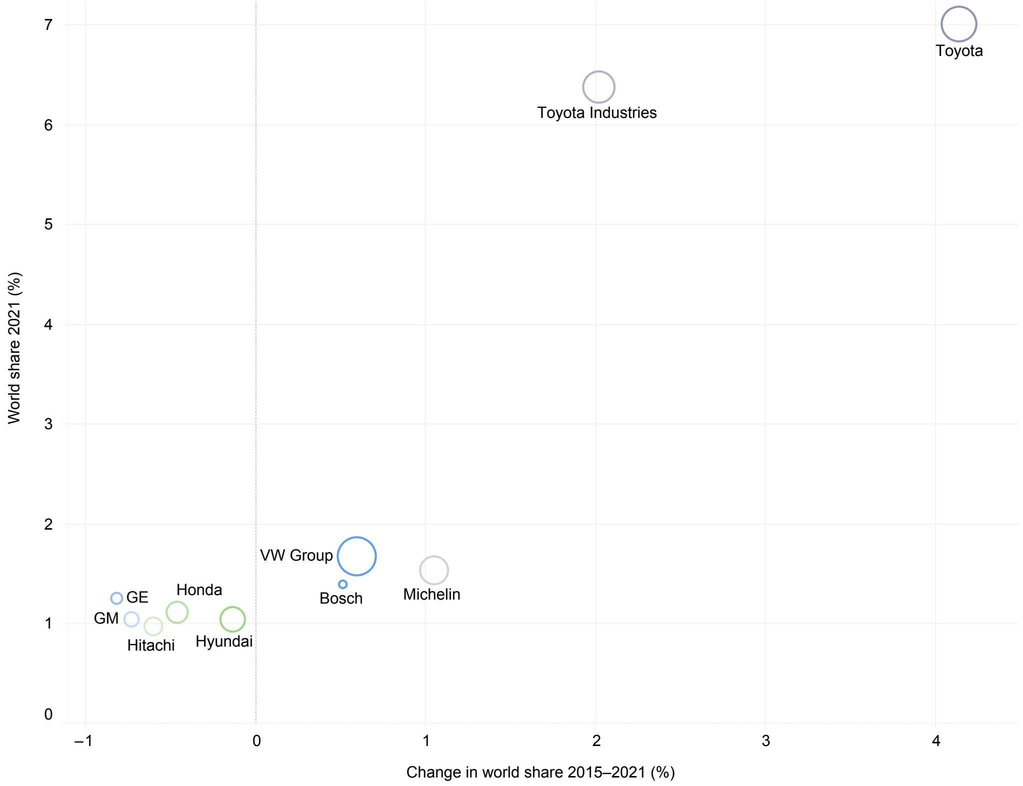
Company	Active patent portfolios	2000	2005	2010	2015	2019	2021	2015	2016	2017	2018	2019
Toyota		3	4	27	29	61	100	4	6	7	19	22
Toyota Industries		9	6	22	44	60	91	4	7	8	15	16
VW Group		3	2	4	11	17	24	1	0	4	5	4
Michelin		3	5	6	5	14	22	0	0	2	6	7
Bosch		5	3	7	9	14	20	1	1	4	2	4
GE		1	6	13	21	23	18	2	2	0	0	0
Honda		0	6	11	16	13	16	0	3	0	5	1
GM		1	7	15	18	15	15	0	0	0	4	0
Hyundai		2	2	6	12	15	15	0	2	0	1	0
Hitachi		21	18	14	16	14	14	2	0	0	0	0
Volvo		1	5	11	15	11	13	1	0	1	3	0
Panasonic		3	9	12	9	11	13	0	1	0	2	2
Bloom Energy		0	0	1	7	9	12	1	0	0	2	1
Carrier		0	1	3	2	5	12	0	2	0	1	7
Kion Group		0	9	13	17	13	11	1	1	0	1	0
Tianjin Xinqing Power Tech		0	0	0	0	0	10	0	0	0	0	0
Komatsu		13	12	2	10	10	9	1	2	0	0	0
Beijing Zhiyang Cloud Technology		0	0	0	11	9	9	0	0	0	0	0
Daewoo Shipbuilding & Marine Engineering		0	0	0	7	10	9	1	3	1	1	0
FJ Dynamics Tech		0	0	0	0	5	9	0	0	0	9	0

Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

The competitive environment shows Toyota and Toyota Industries in front of the field by a long distance and able to extend their lead through the large increases in the world share they have enjoyed in recent years. Michelin, Bosch and VW Group are the only three other players to have increased their world shares. By contrast, the smaller top 10 players have seen shares decrease with stagnating patent portfolios. What is more, the overall gains made in global shares were lower than those made by the two leading players, meaning the gap between Toyota and Toyota Industries and their competitors has widened during the period in question.

Figure 47. **World share of active patents by company compared to all players in the field of special vehicles and the change in this world share between 2015–2021.**

Toyota has the highest increase in world share by over 4 percent, followed by Toyota Industries, while the rest of the players are concentrated between roughly the same world share.



Source: WIPO, based on patent data from Lexis Nexis PatentSight up to March 2022.

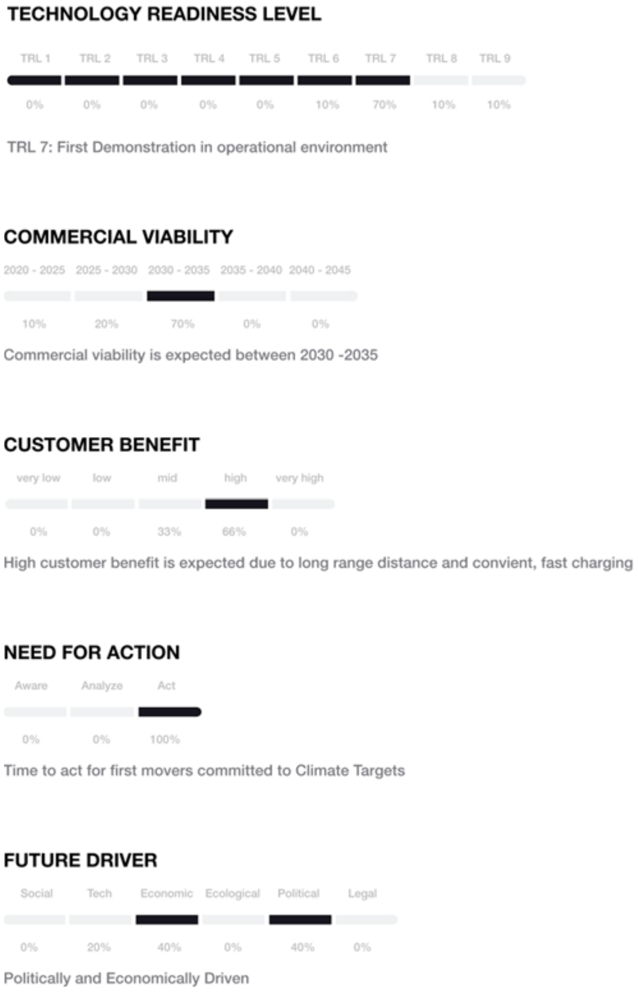
The future of fuel cell technologies in transport

Continuing growth in the hydrogen transportation industry depends on many factors, prominent among which are increasing technological maturity, a significant reduction in the cost of renewable energy and an increasing acceptance of its potential in achieving decarbonization targets. Until now, the challenge of transitioning hydrogen from research and development to commercial reality has largely related to economics and infrastructure. As a consequence, for a long time hydrogen transportation applications have remained within the realm of early prototypes.

This chapter provides insights gleaned from current projections for the future of hydrogen fuel cell transportation and the landscape ahead. Five main criteria – technology readiness level, commercial viability, customer benefit, need for action and future drivers – will be the subject of analysis. This goes beyond the typical time scope of patent analysis and aligns the findings described in the previous chapters with an analysis of relevant news and quarterly financial reporting information, proclamations and other non-patent disclosures. The evaluation of technology readiness, commercial viability, customer benefit and need for action from available sources outside patents aims to complement the patent landscape with the news landscape and the stories described therein.

Figure 48. Brief technology assessment of hydrogen technologies in transport. (See Glossary for a detailed description of the five assessments.)

Different types of assessments give an estimation of the future of hydrogen technologies in transport.



TECHNOLOGY READINESS LEVEL

TRL 7: First Demonstration in operational environment

COMMERCIAL VIABILITY

Commercial viability is expected between 2030 -2035

CUSTOMER BENEFIT

High customer benefit is expected due to long range distance and convient, fast charging

NEED FOR ACTION

Time to act for first movers committed to Climate Targets

FUTURE DRIVER

Politically and Economically Driven

Technology readiness level (TRL)

The technological advances of the last three years have shown the first hydrogen fuel cells prototypes with commercial applications in transportation to be a minimum viable product (corresponding to a TRL 7 in the related NASA model scale ranging from 1 to 9, explained in the glossary). In particular, Toyota's landmark passenger vehicle Mirai has served as a technical demonstration that a 1,360 km trip is possible on a single tank of hydrogen taking five minutes to fill. Strenuous efforts by Toyota and Hyundai in buses and trucks have already resulted in first deliveries, although series production is not expected until later. First tests have been carried out in shipping for ferries and cruise ships, although short-distance fuel cell vessels are not as yet commercially available. Aviation applications will require a few more years until they reach the technological maturity of road and ship applications, despite first test flights having been announced for 2022 by Universal Hydrogen. On the other hand, rail and track applications have proved to be applicable in real environments since 2020. Trains from Alstom, for instance, are to be put into service sometime in 2022, but other rail and track companies have indicated that commercial maturity will come later. Analysis of the patent landscape indicates an increasing number of inventions with new technological advancements, not only in regard to the product but also on the process side to reduce manufacturing and material costs.

Patent perspective

Patenting in the field of fuel cells has a long history stretching back to even before 1960. Generally, patents follow a set pattern as a technology reaches maturity. First, general procedures are claimed, followed by an intensive search for ingredients and elements. New designs and alternatives are developed and spur even more inventive activity. At a certain stage of development it is expected market opportunities will come into play and the number of applications patents, as well as production process patents, start to grow. In reality, the technology is often well in advance of market readiness. We can see in the fuel cells patent development a typical period of high hopes (2005), followed by a huge depression (2010), followed by further hype raising expectations even higher. Currently, the field is buoyed by a second wave of high expectations and increased patenting activity in relation to applications, such as for cars, trucks, ships and special vehicles. At the same time, a growing number of patents are appearing related to process and automation, as well as fuel cell management, supervising and steering. Also, we see the first rise in fuel cell recycling.

All in all, the patent development demonstrates clearly we are in the middle of the market development of a technically advanced technology. All news or voluntary disclosures made by companies around the globe match perfectly the patent landscape, in the form of strategic decision either to fully embrace the technology or simply stay away. However, we can also see that even those companies intending to stay away (for now) have not put a complete stop to research and development, as reflected on their continued related patenting activity.

Patents are usually considered as highlighting the near future, with inventions typically having a timeline of between two and five years from invention filing to market entrance, depending on the technology. Market and business strategies aim for success within the next one to two years and are often two to three years ahead of the patent strategy. As a result, and from what we can tell from the analysis of patent development and news on fuel cells in transportation, we might see remarkable development in the very near future. However, in the view of the late-stage development of the technology and its high degree of maturity, factors such as infrastructure, political decision-making and global uncertainties leave us unsure about when this will happen. One thing is certain in mind is that when it comes to the decarbonization of one of the largest climate gas contributors, namely, the transportation of goods and people, there are very few realistic options other than hydrogen in the long term.

Commercial viability

As technological maturity rises, companies face the challenge to mass-producing hydrogen transportation applications. Since carbon emission targets are determined for each application area, the source of hydrogen needs to be green and must be produced by renewable energy. Next to clean hydrogen, infrastructure need to have charging stations in place so that consumers can access to hydrogen for refueling cars and taxis, trucks, ships, trains and aircraft. Moreover, the cost of fuel cells is currently high and needs to be reduced through material improvements and manufacturing process optimization. The implications of further technological advances, improvement in infrastructure and factors like CO_2 pricing, have led companies – especially in the automotive and truck industry – to anticipate commercial viability anytime from 2025 to 2030. Due to higher amortization cycles, greater cost reductions and further research and development, the shipping industry project is expecting commercial viability sometime around 2040. The same applies for aviation applications, although short-distance aircraft and hydrogen-based synthetic kerosene could start becoming commercially viable a decade earlier at around 2030. Based on the latest announcements in the rail and track industry, it is expected hydrogen transportation will be commercially available sometime between 2025–2030. However, should expectations be raised regarding, for instance, the learning curves of technological advancements, how quickly infrastructure is installed, the level of subsidies in hydrogen transport, increasing CO_2 prices or investment volumes, companies can be expected to modify what they have already announced accordingly.

Customer benefits and problems

Compared to battery electric applications, fuel cell applications have advantages for customers with regard to a longer distance travelled on a tank of fuel and shorter charging cycles. However, to make these commercially available, there are specific challenges to be overcome. For instance, charging a fuel cell vehicle will have to take no more than three to five minutes, a similar amount of time to gasoline vehicles. Compared to BEVs, fuel cell vehicles currently charge 8–10 times faster. Hydrogen fuel cells have a far greater energy storage density than lithium-ion batteries, offering a significant range advantage for electric vehicles while also being lighter and occupying less space. The fuel cell-based Toyota Mira has currently nearly twice the range of the Lucid Air BEV. But the pricing for a fuel cell vehicle is currently quite high and unaffordable in the broader context. The most affordable BEV costs around 24,000 euros, whereas a basic Toyota Mirai costs around 63,000 euros, making fuel cell vehicles 2.5 times more expensive than BEVs at today's prices. There are, however, other related topics to explore more fully, such as safety (Bethoux, 2020).

In aviation, companies are working on advances in light-weight storage tanks and cryogenic cooling systems in order to exploit hydrogen's high energy density. Short-range and unmanned flying craft are closer to realization, since they demand smaller amounts of an energy carrier.

The storage of hydrogen is as much of a challenge for maritime shipping as it is for aviation. More testing is needed on the safety aspects of the handling, storage and bunkering of hydrogen on large vessels. In shipping, lively discussion is underway on the use of liquid ammonia as fuel of choice, which fits well with the industrial infrastructure currently available at harbors.

Need for action

To get transportation on track in Net Zero scenarios, the implementation of a broad set of policies, technological advancements and new markets are crucial. Hydrogen technology is a viable solution to decarbonizing a transportation sector currently responsible for one-quarter of direct CO_2 emission from combustible fuel. Since hydrogen has advantages in terms of the storage of long-term energy, dilutes dependency on fossil fuels and is a viable energy source complying with future climate targets, companies and governments wanting to build on these advantages as a first mover could be expected to act now.

Future drivers

It has been decades since hydrogen was first proposed as a primary source of clean energy. Thanks to advances in several key technologies, the time for this abundant gas to contribute to the fight against climate change may have finally arrived. But the level of expectation and hype is high, and there are still many technological, economic and policy challenges to be met before hydrogen can offer a truly cost-effective way of reducing greenhouse gas emissions. If hydrogen is to realize its full potential, it must become less expensive and more efficient to produce, distribute and use. To achieve this goal, two key drivers need to play a part, namely, economics and politics.

Economic drivers

If the hydrogen economy is to become a reality, companies and stakeholders throughout the ecosystem need to take action. Moving to a zero-emissions future represents a massive challenge for the energy and transportation industries, including automotive, aviation, shipping and rail. The electrification of the transportation sector by introducing alternative power trains and their related energy concept is becoming a choice between battery and fuel cell applications. Although complementary in many ways, the enormous investments in research and development, production and infrastructure required by both, combined with what is required to manage a scale-up, means making the wrong decision could potentially endanger the future of established companies across application areas and regions. It is likely that investments will pay out for one of the two alternatives in the respective application areas, but only if they are able to achieve scale. Advantages in scaling will be burdensome to catch up with.

The choice of alternatives for replacing fossil fuel divides the automotive industry, including passenger cars and trucks. Whereas the world's largest manufacturers (by volume and value), Volkswagen Group and Tesla, are focusing solely on BEVs, the second largest, Toyota, as well as companies such as Hyundai, GWM and some others, have made fuel cell vehicles core to their business strategy. The divide in strategies is quite controversial – and contentious: Elon Musk of Tesla has described hydrogen as "staggeringly dumb." However, even a dual strategy like the one pursued by companies such as BMW, Daimler and GM can create risk, if it dilutes the focus, development speed and scale required for success. That said, although pursuing a dual strategy could prove capital-intensive and far more complex to manage than simply focusing on one, it could nevertheless pay out in terms of knowing where best to apply either of the two power-train technologies.

Anticipating the question as to which automotive application is likely to be most suitable for hydrogen-powered fuel cell vehicles, heavy-duty trucks is the most obvious application for initial deployment. Moreover, the large scale and diversity of the truck market is such that it could also act as enabler to passenger vehicle applications. Observing this trend will be decisive for the whole sector.

However, if both battery electric and fuel cell vehicle applications attain equivalent capabilities in terms of lifetime, range, handling of cold weather, vibration and refueling/recharging times, and further assuming there will be an equivalent degree of regulation for both, three decisive factors remain:

- **Infrastructure** needs to be built up. Charging times are critical, especially for commercial vehicles, be they trucks, buses or taxis. Every minute a vehicle is off the road, it is losing money. Thus, minimizing charging time is vital for the electrification of the transportation sector.

- **Autonomous driving** is expected to gain market share during this decade and has the transformative potential to disrupt current business models. In the context of a circular economy, where people tend to use a car instead of owning one, technologies that avoid high maintenance and have a long-range capability are more significant.

- The **payload** also needs to be considered when making decisions, if high-energy demands and long-range requirements play a critical role.

From this we can conclude that a hydrogen economy is likely to develop with competitive pricing independent of the automotive industry, and that BEVs will be impacted by relatively high charging prices due to increasing generation costs, high infrastructure investments and competitive market dynamics.

That said, there are, of course, additional factors that come into play, such as potential advances in related technology areas like solid-state batteries (IEEE Spectrum, 2021; EPO and IEA, 2020), new regulatory bodies and decisions taken on the use of nuclear energy, which could all impact local energy generation and the wider use of hydrogen.

Political drivers

Besides the economic factors, government, policymakers and regulators all have a crucial role to play in decarbonizing the transportation sector. Examples from Europe, China and the Republic of Korea show hydrogen to be a key element in strategies designed to reach zero emissions by 2050. Continued support through direct subsidies and policy changes will underpin the production and use of green hydrogen in applications where hydrogen offers the greatest potential for reducing greenhouse gas emissions. However, although many of the strategies for adopting hydrogen technologies focus on the deployment of hydrogen production, only a few place an emphasis on the use of hydrogen. If hydrogen use is not promoted for applications like long-distance transport, shipping, aviation and further industrial applications, companies are less likely to direct their focus toward hydrogen. Today, green hydrogen is more costly to use than fossil fuels. Some countries are choosing to impose higher carbon prices in order to close this commercial viability gap, making decarbonizing the transport sector through hydrogen use attractive to investors and companies alike.

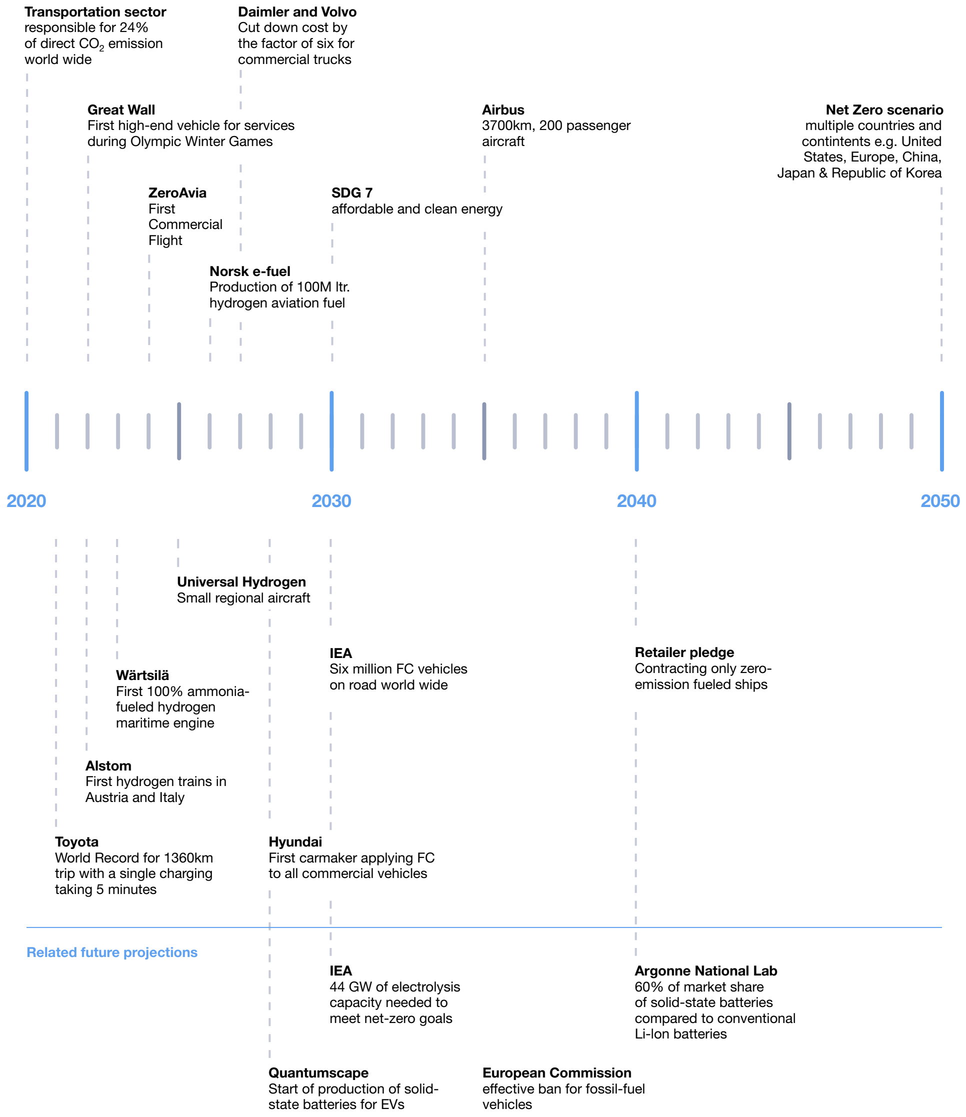
Current projections provide insights into limiting global warming to 1.5°C or as close as possible, a target backed by the Paris Agreement and in line with dire warnings in the UN Intergovernmental Panel on Climate Change (IPCC) special report published in 2021, and which requires further efforts be made (IPCC, 2021). A 1.5°C pathway demands a rapid and global transformation of energy systems in support of a 6 percent annual emissions reduction. This can only be realized through greater investment in green technology, a significant increase in the use of renewable power sources and the electrification of just about everything. The path from 2°C to a 1.5°C scenario means that far greater solar and wind capacity has to be part of the solution by 2030 – hydrogen could serve as a fourth pillar in a solar, wind and hydro-powered world. Faster cost reductions and the early commercial viability of hydrogen in many transportation application areas can play a significant role in hydrogen's deployment and scaling up.

Roadmap and market outlook for hydrogen technologies in transport

Selected future-oriented statements made by companies, organizations and policymakers give a glimpse into a projected future for hydrogen fuel cells in transportation (Figure 49).

Figure 49. Hydrogen fuel cell in transportation roadmap, 2020–2050.

Different statements of projections provide an outlook of the future transportation market and technological developments.



Annex

Glossary

Patent measures

Filing date: We measured the first filing date in a patent family and plotted the first filing date of a family from when the patent was first introduced. We did not use the first or oldest priority date, since several of these priority patent applications are never published. In a majority of cases, filing date and priority date do not differ. Therefore, filing date typically marks the date when the invention was first delivered at the patent office.

Patent applicant: Patents are filed by an applicant, which can be organization or a natural person. Applicants are not inventors, even if sometimes they are similar. The applicant is in most jurisdictions (except in a few cases, for example, the U.S.) and in most cases published with the patent and remains always the *applicant*. Applicants are often misspelled or incorrectly reproduced in patent publications. In addition, the applicant is not automatically, and must never be, similar to the owner or the probable owner of a patent at a given time, even if that is often the case. Patents can be transferred or sold, or the applicant itself can be sold as a company in a merger or takeover. Therefore the “owner” of a patent might change over time and it is not always published. For proper analysis, to consolidate incorrect spelling and to include merger and acquisition information in the analysis, the report used whenever appropriate the ultimate owner concept by PatentSight for higher relevancy. The most probable entity was then named as *OWNER.*

Patent application: Whenever a patent application is filed in a jurisdiction, including the international Patent Cooperation Treaty (PCT) route administered by WIPO or the European Patent Convention route (EP) administered by the European Patent Office (EPO), it is given a filing date. The term *patent application*s must not be confused with *applications*, as applied innovations are often also named applications (e.g., a new innovative wheel for a car is the application of wheel technology for the application “road vehicle”).

Patent family: A patent family is a collection of patent applications covering the same or similar technical content and all sharing one or more priority documents. There are several definitions of patent families, including simple and extended patent families (EPO, n.d.; WIPO, 2013), depending on the number of priority documents shared (ranging from one to all priority documents). Patent family members are the individual patent rights filed in those jurisdictions where a patent applicant is seeking patent protection (e.g., WIPO, EPO) and all publications in relation to these (patent publications with kind codes A1, A2, B1, and so on). In the present study, we are counted patent families (using a representative patent family member for each patent family), unless otherwise specified, as we wanted to count inventions and not several patent documents referring to the same subject matter. In accordance to this definition, we use the terms patents, patents filings or patent families for *inventions (= simple patent family).* Only in rare cases we analyze *individual or national patent filings* and indicate these in the text.

Reporting date concept: The reporting date concept used was developed by PatentSight and makes it possible to “travel back in time” and analyze the patent landscape as it was in the past. Each reporting date is the moment in time at which the evaluation of a patent portfolio or a patent family was done. The *current* reporting date shows the state of the world as it is now. For any selected reporting date, only patent families that were active on that particular date are taken account of for the analysis. Active patent families are defined as all patent families with at least one alive member – this can be either a pending patent application or an active granted (i.e., in force) patent. Moreover, for any reporting date selected, no information other than what was already available at that point in time is considered. The only exception is patent ownership information – for any given reporting date, the owner of a patent family is always the current ultimate owner, even if the patent family belonged to a different entity in the past. Moreover, in those cases where information should have been available at a past date or where data have been corrected, information may change retrospectively.

For the correct evaluation of patent portfolios, it is crucial to know the current owner of each patent family. This report used the PatentSight standardized applicant field referred to as “ultimate owner,” assigning the current owner at a patent family and consolidated level, after manually harmonizing and normalizing applicants, reviewing the corporate structure of a company, and considering all reassignments, mergers and acquisitions which may lead to a portfolio under the standardized applicant/patent owner.

Foresight indicators

Driven by increased pressure to innovate and a greater need for strategic alignment, it is of great importance that companies and policymakers deal with developments in the business environment at an early stage to provide orientation knowledge for sound, strategic decisions (Burmeister *et al.*, 2004; Costanzo and MacKay, 2009; Müller and Müller-Stewens, 2009; Müller-Stewens and Müller, 2010; Rohrbeck, 2011).

Courtney (2001) has suggested that in today’s environment, it is necessary to establish strategic foresight in order to be competitive in the future. For this purpose, procedures and processes have to be implemented in order to identify developments and breaks in trends at an early stage, for example, through emergent technologies, new legislation and changing customer needs, in order to shift industry boundaries or capture new markets (Ansoff, 1976). Strategic foresight supports companies and policymakers in systematically generating new orientation knowledge, knowledge about the immediate market environment, as well as the broad socioeconomic, technological, environmental and political business environment, in order to gain a better understanding of its future, including a concrete idea of the risks the company faces, as well as opportunities that can be exploited.

Strategic foresight is fundamentally based on the assumptions of trend and future research. Trend research is generally understood to mean the identification and interpretation of social, economic, technological and cultural developments (Burmeister *et al*., 2004; Müller and Müller-Stewens, 2009). A distinction must be made between a socio-economic and a mathematical understanding of trends, that is, the accumulation of events and developments and the mathematical-statistical time series (Mićić, 2006).

In this report, strategic foresight represents a framework construct for fulfilling the task of data and indicator driven analysis. Through it, current developments in a business environment are obtained so they can be made available to decision-makers. The goal is to accelerate the responsiveness of decision-making (Passing, 2017). This approach is based on an analytical understanding and can be subdivided into the process steps of observation, analysis and evaluation of new information (Müller-Stewens and Müller, 2010). Thus, strategic foresight deals with probable futures that can be anticipated exploratively on the basis of early detection of weak signals (Ansoff, 1976; Krystek and Müller-Stewens, 2006; Müller-Stewens and Müller, 2010). Within this report we used the following foresight indicators:

Commercial viability: Taking current data from research developments, maturity of intellectual property and company statements into account, in order to determine when the commercial phase of a new technology is likely to be ready for broader application. Commercial viability is predicted so as to provide companies, organizations and policymakers with data-driven insights for decision-making.

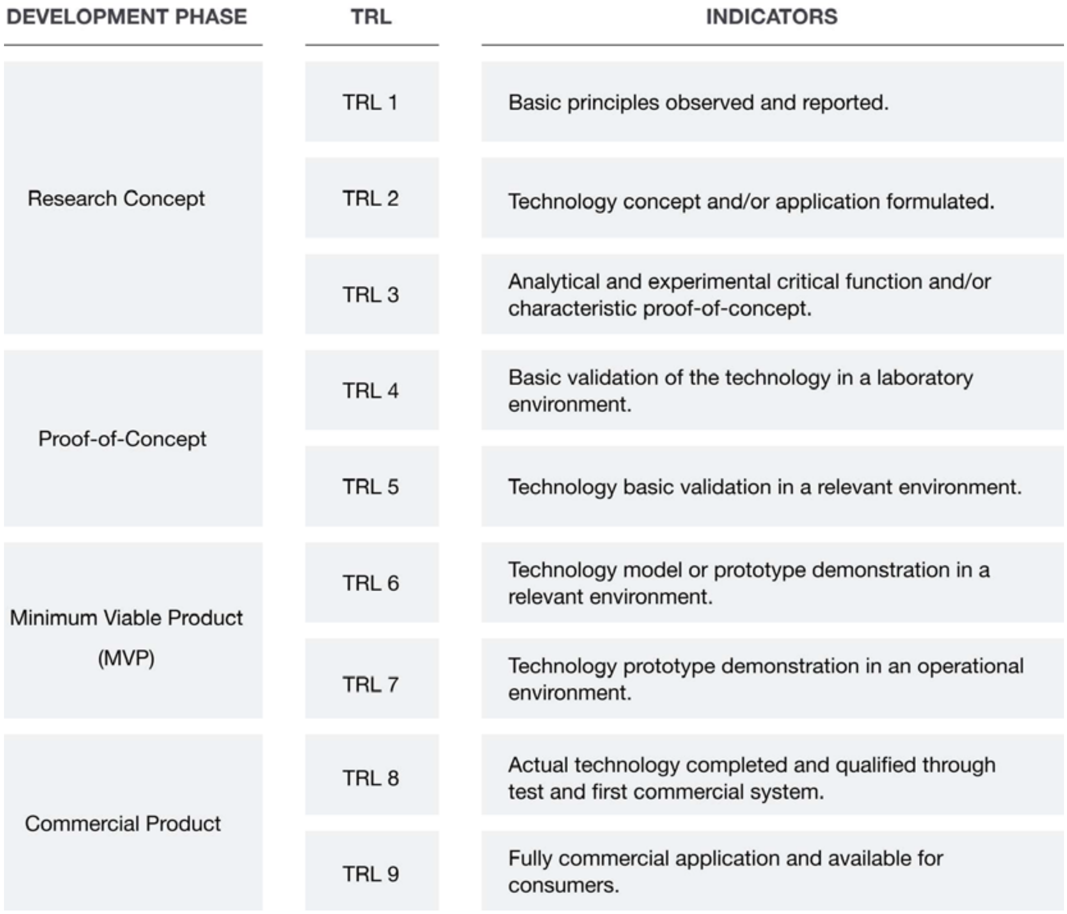
Customer benefits: Customer benefit is calculated according to sentiments toward technologies. If a technology provides several direct advantages for users and customers, and is frequently reported as a benefit, the methodology takes this into account and validates it based on future buying decisions.

Future drivers: Knowing what will be the future drivers behind technological development helps companies develop the right strategic narrative and motives for communicating their activities. The STEEP-approach (social, technological, economic, environmental and political) describes a framework of macro-environmental factors and gives an overview of the different macro-environmental factors to be taken into consideration (see, e.g., Johnson and Scholes, 2000). It is a strategic tool for understanding market growth or decline, business position, potential and direction for operations.

Need for action: Considering innovation as the sum of invention and market penetration, we predict the need for action by companies, organizations and policymakers wanting to achieve a competitive edge through the introduction of a new technology onto the market. Based on product development cycles and investment opportunities into technologies, insights are provided into the need for action in three categories: “wait and see,” “analyze” and “act.”

Technology readiness level (TRL): A system used to estimate the maturity of a technology popular with corporations and national organizations. The model was initially published by NASA but has since been adapted to multiple technological fields in recent years (NASA, 2021b). The TRL is based on a scale from 1 to 9, with 9 being the most mature technology. The use of TRLs to assess the maturity of a new technology enables consistent, uniform discussions of technical maturity across different types of technology (see Figure A1).

Figure A1.



DEVELOPMENT PHASE	TRL	INDICATORS
Research Concept	TRL 1	Basic principles observed and reported.
	TRL 2	Technology concept and/or application formulated.
	TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept.
Proof-of-Concept	TRL 4	Basic validation of the technology in a laboratory environment.
	TRL 5	Technology basic validation in a relevant environment.
Minimum Viable Product (MVP)	TRL 6	Technology model or prototype demonstration in a relevant environment.
	TRL 7	Technology prototype demonstration in an operational environment.
Commercial Product	TRL 8	Actual technology completed and qualified through test and first commercial system.
	TRL 9	Fully commercial application and available for consumers.

Patent searches

Fuel cells in transport

Part 1
(Tag=(“*SOFC Fuel Cells*”, “*DMFC, DAFC, Direct or Reforming Fuel Cell*”, “*AMFC Alkaline Membrane Fuel Cells”*, “*PAFC Phosphoric Acid Fuel Cells*”, “*MCFC Molten Carbonate Fuel Cells*”, “*Fuel Cell*”, “*PEM Fuel Cells*”, “*Fuel Cell Manufacturing, Stacking*”) AND (CPC=(B60, B62, Y02T 10, Y02T 90/14, Y02T 90/16) OR IPC=(B60, B62))) AND (TitleAbstractClaims=(fuel_cell* OR HT_PEM* OR DMFC OR DAFC OR FC OR gas diffusion NEAR3 (membran* OR electrode*) OR bipolar NEAR3 plate*) OR TitleAbstractClaimsDescription=(fuel_cell* OR HT_PEM* OR DMFC OR DAFC OR gas diffusion NEAR3 (membran* OR electrode*) OR bipolar NEAR3 plate*)) OR CPC=(B60L 3/0053, B60L 11/1881, B60L 50/70, B60L 50/75, B60L 53/54, B60L 58/30, B60L 58/40, B60W 10/28, B60W2510/28, B60W2710/28, B60Y2400/202, H01M2250/20, Y02T 90/30, Y02T 90/32, Y02T 90/34, Y02T 90/40, Y10S 903/908) OR IPC=(B60L 50/70, B60L 50/75, B60L 53/54, B60L 58/30, B60L 58/40, B60W 10/28)

Part 2
((Tag= (“*SOFC Fuel Cells*”, “*DMFC, DAFC, Direct or Reforming Fuel Cell*”, “*AMFC Alkaline Membrane Fuel Cells”*, “*PAFC Phosphoric Acid Fuel Cells*”, “*MCFC Molten Carbonate Fuel Cells*”, “*Fuel Cell*”, “*PEM Fuel Cells*”, “*Fuel Cell Manufacturing, Stacking*”) OR CPC=(Y02T 90/30, Y02T 90/40) OR TitleAbstractClaims=(fuel_cell* OR HT_PEM* OR DMFC OR DAFC OR FC OR gas diffusion NEAR3 (membran* OR electrode*) OR bipolar NEAR3 plate*)) AND (CPC=(B60, B60L 50/30, B60L 50/40, B60L 50/60, B60L 50/70, B60L 50/75, B60L 53/00, B60L 53/10, B60L 53/20, B60L 58/00, B62, B66F 9/06, E02F, Y02T 10, Y02T 90/14, Y02T 90/16) OR IPC=(B60, B60L 50/30, B60L 50/40, B60L 50/60, B60L 50/70, B60L 50/75, B60L 53/00, B60L 53/10, B60L 53/20, B60L 58/00, B62, B66F 9/06, E02F) OR Tag=(“EconSight Technology Fields\M1.1.1. Electrical, Solar, Fuel Cell Aircraft”, “EconSight Technology Fields\M1.3.4. Electric Vehicles”)))

Part 3
(Tag= (“*SOFC Fuel Cells*”, “*DMFC, DAFC, Direct or Reforming Fuel Cell*”, “*AMFC Alkaline Membrane Fuel Cells”*, “*PAFC Phosphoric Acid Fuel Cells*”, “*MCFC Molten Carbonate Fuel Cells*”, “*Fuel Cell*”, “*PEM Fuel Cells*”, “*Fuel Cell Manufacturing, Stacking*”) OR CPC=(Y02T 90/30, Y02T 90/40)) AND (TitleAbstractClaims=(pkw OR automotiv* OR automobil* OR road NEAR3 vehicle* OR personal mobility device OR bus OR public transport OR tram OR truck OR omnibus OR car OR cars OR lkw OR (lorry OR lorries) NEAR3 vehicle* OR scooter* OR motor_cycle* OR tuk_tuk* OR auto_rickshaw* OR load SEQ2 transporting OR (heavy_load* OR long_range*) NEAR3 vehicle* OR hydrogen electric truck* OR freight vehicle* OR vehicle_train* OR (commercial OR utility) NEAR3 vehicle* OR electric vehicle* OR BEV OR (only OR battery OR all OR pure) SEQ3 electric NEAR5 (vehicle* OR car OR automotiv* OR automobil* OR Road_going OR passenger_vehicle*) OR BEV OR PHEV OR FCEV OR transport NEAR3 truck* OR buses OR transporter* OR (construction OR off-road* OR farm) NEAR3 vehicle* OR load NEAR3 (transporting OR bearing) NEAR5 (Carriage* OR vehicle*)) OR TitleAbstractClaims=(scooter* OR motor_cycle* OR tuk_tuk* OR auto_rickshaw* OR load SEQ2 transporting OR (tow SEQ2 bar) NEAR3 vehicle* OR aircraft NEAR3 (tug* OR tow*) OR trucks OR (heavy_load* OR long_range*) NEAR3 vehicle* OR hydrogen electric truck* OR freight vehicle* OR vehicle_train* OR (commercial OR utility) NEAR3 vehicle* OR crane* OR bulldozer* OR grader* OR excavator* OR tractor* OR bagger* OR dredger* OR person* NEAR4 drone* OR human* NEAR4 drone* OR people* NEAR4 drone* OR personal* NEAR4 flying* OR manned* NEAR4 aerial* OR aerauto* OR aerocar* OR aero_taxi* OR vtol OR passenger NEAR3 drone* OR evtol OR stol OR stovl OR transport NEAR3 truck* OR buses OR transporter* OR aircraft* OR airplane* OR helicopter* OR drone* OR air_ship* OR HAPS OR Low_orbit* OR zeppelin* OR satellite* OR person* NEAR4 drone* OR human* NEAR4 drone* OR people* NEAR4 drone* OR personal* NEAR4 flying* OR manned* NEAR4 aerial* OR aerauto* OR aerocar* OR aero_taxi* OR vtol OR passenger NEAR3 drone* OR evtol OR stol OR stovl OR aeroplane*) OR TitleAbstractClaims=(train OR trains OR railway* OR railroad* OR tramway* OR tram OR track_bound* OR (track OR tracks OR rail) SEQ2 vehicle* OR track_side* OR locomotive*) OR TitleAbstractClaims=(ship OR ships OR ship_building* OR marine OR maritim OR ocean* OR water_borne* OR sub_sea OR sub_marine* OR tanker OR sea transport* OR boat OR shipping OR ship_building* OR marine OR maritim OR ocean* OR

water_borne* OR water_vehicle* OR tanker OR sea transport* OR boat OR shipping OR marine) OR TitleAbstractClaims=((forklift* OR fork_lift* OR (airport* OR harbour* OR load SEQ2 transporting OR tow SEQ2 bar) NEAR3 vehicle* OR aircraft NEAR3 (tug* OR tow*)) OR crane* OR bulldozer* OR grader* OR excavator* OR tractor* OR bagger* OR dredger*))

Part 4

(Tag= ("*SOFC Fuel Cells*", "*DMFC, DAFC, Direct or Reforming Fuel Cell*", "*AMFC Alkaline Membrane Fuel Cells*", "*PAFC Phosphoric Acid Fuel Cells*", "*MCFC Molten Carbonate Fuel Cells*", "*Fuel Cell*", "*PEM Fuel Cells*", "*Fuel Cell Manufacturing, Stacking*") AND TitleAbstractClaimsDescription=((pkw OR automotiv* OR automobil* OR road NEAR3 vehicle* OR personal mobility device OR bus OR public transport OR tram OR truck OR omnibus OR car OR cars OR lkw OR (lorry OR lorries) NEAR3 vehicle* OR scooter* OR motor_cycle* OR tuk_tuk* OR auto_rickshaw* OR load SEQ2 transporting OR (heavy_load* OR long_range*) NEAR3 vehicle* OR hydrogen electric truck* OR freight vehicle* OR vehicle_train* OR (commercial OR utility) NEAR3 vehicle* OR electric vehicle* OR BEV OR (only OR battery OR all OR pure) SEQ3 electric NEAR5 (vehicle* OR car OR automotiv* OR automobil* OR Road_going OR passenger_vehicle*) OR BEV OR PHEV OR FCEV OR transport NEAR3 truck* OR buses OR transporter* OR (construction OR off-road* OR farm) NEAR3 vehicle* OR load NEAR3 (transporting OR bearing) NEAR5 (Carriage* OR vehicle*) OR scooter* OR motor_cycle* OR tuk_tuk* OR auto_rickshaw* OR load SEQ2 transporting OR (tow SEQ2 bar) NEAR3 vehicle* OR aircraft NEAR3 (tug* OR tow*) OR trucks OR (heavy_load* OR long_range*) NEAR3 vehicle* OR hydrogen electric truck* OR freight vehicle* OR vehicle_train* OR (commercial OR utility) NEAR3 vehicle* OR crane* OR bulldozer* OR grader* OR excavator* OR tractor* OR bagger* OR dredger* OR person* NEAR4 drone* OR human* NEAR4 drone* OR people* NEAR4 drone* OR personal* NEAR4 flying* OR manned* NEAR4 aerial* OR aerauto* OR aerocar* OR aero_taxi* OR vtol OR passenger NEAR3 drone* OR evtol OR stol OR stovl OR transport NEAR3 truck* OR buses OR transporter* OR railway* OR railroad* OR tramway* OR tram OR track_bound* OR (track OR tracks OR rail) SEQ2 vehicle* OR track_side* OR locomotive* OR aircraft* OR airplane* OR helicopter* OR drone* OR air_ship* OR HAPS OR Low_orbit* OR zeppelin* OR satellite* OR person* NEAR4 drone* OR human* NEAR4 drone* OR people* NEAR4 drone* OR personal* NEAR4 flying* OR manned* NEAR4 aerial* OR aerauto* OR aerocar* OR aero_taxi* OR vtol OR passenger NEAR3 drone* OR evtol OR stol OR stovl OR aeroplane* OR ship OR ships OR ship_building* OR marine OR maritim OR ocean* OR water_borne* OR sub_sea OR sub_marine* OR tanker OR sea transport* OR boat OR shipping OR ship_building* OR marine OR maritim OR ocean* OR water_borne* OR water_vehicle* OR tanker OR sea transport* OR boat OR shipping OR marine) NEAR5 ((fuel_cell*) OR ((hydrogen OR H2) SEQ2 electric*)))) OR TitleAbstractClaims=((pkw OR automotiv* OR automobil* OR road NEAR3 vehicle* OR personal mobility device OR bus OR public transport OR tram OR truck OR omnibus OR car OR cars OR lkw OR (lorry OR lorries) NEAR3 vehicle* OR scooter* OR motor_cycle* OR tuk_tuk* OR auto_rickshaw* OR load SEQ2 transporting OR (heavy_load* OR long_range*) NEAR3 vehicle* OR hydrogen electric truck* OR freight vehicle* OR vehicle_train* OR (commercial OR utility) NEAR3 vehicle* OR electric vehicle* OR BEV OR (only OR battery OR all OR pure) SEQ3 electric NEAR5 (vehicle* OR car OR automotiv* OR automobil* OR Road_going OR passenger_vehicle*) OR BEV OR PHEV OR FCEV OR transport NEAR3 truck* OR buses OR transporter* OR (construction OR off-road* OR farm) NEAR3 vehicle* OR load NEAR3 (transporting OR bearing) NEAR5 (Carriage* OR vehicle*) OR scooter* OR motor_cycle* OR tuk_tuk* OR auto_rickshaw* OR load SEQ2 transporting OR (tow SEQ2 bar) NEAR3 vehicle* OR aircraft NEAR3 (tug* OR tow*) OR trucks OR (heavy_load* OR long_range*) NEAR3 vehicle* OR hydrogen electric truck* OR freight vehicle* OR vehicle_train* OR (commercial OR utility) NEAR3 vehicle* OR crane* OR bulldozer* OR grader* OR excavator* OR tractor* OR bagger* OR dredger* OR person* NEAR4 drone* OR human* NEAR4 drone* OR people* NEAR4 drone* OR personal* NEAR4 flying* OR manned* NEAR4 aerial* OR aerauto* OR aerocar* OR aero_taxi* OR vtol OR passenger NEAR3 drone* OR evtol OR stol OR stovl OR transport NEAR3 truck* OR buses OR transporter* OR railway* OR railroad* OR tramway* OR tram OR track_bound* OR (track OR tracks OR rail) SEQ2 vehicle* OR track_side* OR locomotive* OR aircraft* OR airplane* OR helicopter* OR drone* OR air_ship* OR HAPS OR Low_orbit* OR zeppelin* OR satellite* OR person* NEAR4 drone* OR human* NEAR4 drone* OR people* NEAR4 drone* OR personal* NEAR4 flying* OR manned* NEAR4 aerial* OR aerauto* OR aerocar* OR aero_taxi* OR vtol OR passenger NEAR3 drone* OR evtol OR stol OR stovl OR aeroplane* OR ship OR ships OR ship_building* OR marine OR maritim OR ocean* OR water_borne* OR sub_sea OR sub_marine* OR tanker OR sea transport* OR boat OR shipping OR ship_building* OR marine OR maritim OR ocean* OR water_ borne* OR water_vehicle* OR tanker OR sea transport* OR boat OR shipping OR marine) NEAR5 ((fuel_cell*) OR ((hydrogen OR H2) SEQ2 electric*)))

Part 1 or 2 or 3 or 4 -> "*Fuel Cells in Transport, Precleaned"*

Cleaning step for Parts 1–4, including NOT/NOT Loop -> *"WIPO FC Study\FCTransport All (Cleaned)"*

Tag=("*Fuel Cells in Transport, Precleaned*") AND NOT ((TitleAbstractClaims=((diesel* OR gasoline*) NEAR3 (vehicle* OR automotiv* OR automobil* OR truck*)) OR Tag=("EconSight Technology Fields\WIPO Technology fields\1WIPO_Pharmaceuticals", "EconSight Technology Fields\2E.3.1. Energy Efficient Home Appliances", "EconSight Technology Fields\6P.3.6. Diesel Fuel, Engines", "EconSight Technology Fields\C10.1.7. HVAC, Air conditioning", "EconSight Technology Fields\M1.2.5. Exhaust Catalyst", "EconSight Technology Fields\M1.3.5. Hybrid Vehicles") OR CPC=(H01M2250/10, H01M2250/30, Y02B 90/10, Y02E 60/32, Y02E 60/34, Y02E 60/36) OR IPC=()) AND NOT (IPC=(B60L 50/70, B60L 50/75, B60L 53/54, B60L 58/30, B60L 58/40, B60W 10/28, H01M 8/22) OR CPC=(B60L 3/0053, B60L 11/1881, B60L 50/70, B60L 50/75, B60L 53/54, B60L 58/30, B60L 58/40, B60W 10/28, B60W2510/28, B60W2710/28, B60Y2400/202, H01M 8/22, H01M2250/20, Y02E 60/50, Y02T 90/14, Y02T 90/32, Y02T 90/34, Y10S 903/908) OR TitleAbstractClaims=(fuel_cell* OR HT_PEM* OR DMFC OR DAFC OR sofc OR pafc OR amfc OR fcbev OR fcev)))

Fuel cells in road vehicles

(Tag=("*WIPO FC Study\FCTransport All (Cleaned)*") AND (TitleAbstractClaimsDescription=(pkw OR automotiv* OR automobil* OR road NEAR3 vehicle* OR personal mobility device OR bus OR public transport OR tram OR truck OR omnibus OR car OR cars OR lkw OR (lorry OR lorries) NEAR3 vehicle* OR scooter* OR motor_cycle* OR moped* OR tuk_tuk* OR auto_rickshaw* OR load SEQ2 transporting OR (heavy_load* OR long_range*) NEAR3 vehicle* OR hydrogen electric truck* OR freight vehicle* OR vehicle_train* OR (commercial OR utility) NEAR3 vehicle* OR electric vehicle* OR BEV OR (only OR battery OR all OR pure) SEQ3 electric NEAR5 (vehicle* OR car OR automotiv* OR automobil* OR Road_going OR passenger_vehicle*) OR BEV OR PHEV OR FCEV OR transport NEAR3 truck* OR buses OR transporter* OR (construction OR off-road* OR farm) NEAR3 vehicle* OR load NEAR3 (transporting OR bearing) NEAR5 (Carriage* OR vehicle*)) OR Tag=("EconSight Technology Fields\M1.3.4.2 Electric Road Vehicles, BEV") OR IPC=(B62) OR CPC=(B60Y2200/10, B62, G01R 31/006, G05D2201/0213, Y02T 10) OR CPC=(B60W2510/28, B60W2710/28, Y02T 90/14, Y02T 90/34)))

Fuel cells in trucks (subsegment of road)

(Tag=("*WIPO FC Study\FCTransport All (Cleaned)*") AND TitleAbstractClaimsDescription=(bus OR public transport OR truck OR omnibus OR lkw OR (lorry OR lorries) NEAR3 vehicle* OR load SEQ2 transporting OR (heavy_load* OR long_range*) NEAR3 vehicle* OR hydrogen electric truck* OR freight vehicle* OR vehicle_train* OR (commercial OR utility) NEAR3 vehicle* OR transport NEAR3 truck* OR buses OR transporter* OR load NEAR3 (transporting OR bearing) NEAR5 (Carriage* OR vehicle*)))

Fuel cells in air transport/drones/cosmonautics

Tag=("*WIPO FC Study\FCTransport All (Cleaned)*") AND (TitleAbstractClaimsDescription=(aircr aft* OR airplane* OR helicopter* OR drone* OR air_ship* OR HAPS OR Low_orbit* OR zeppelin* OR satellite* OR person* NEAR4 drone* OR human* NEAR4 drone* OR people* NEAR4 drone* OR personal* NEAR4 flying* OR manned* NEAR4 aerial* OR aerauto* OR aerocar* OR aero_taxi* OR vtol OR passenger NEAR3 drone* OR evtol OR stol OR stovl OR aeroplane*) OR Tag=("EconSight Technology Fields\M1.1.1. Electrical, Solar, Fuel Cell Aircraft", "EconSight Technology Fields\M1.1.2. Aircraft, Aerospace, Helicopter, Vtol", "EconSight Technology Fields\M1.1.4. Cosmonautics", "EconSight Technology Fields\M1.1.5. Drone, AGV, UAV", "EconSight Technology Fields\M1.1.6. VTOL PAV Personal Manned Aerial Vehicle") OR IPC=(B64) OR CPC=(B60G2300/18, B60Y2200/50, B64, Y02T 50))

Fuel cells in railways, tramways

Tag=("*WIPO FC Study\FCTransport All (Cleaned)*") AND (TitleAbstractClaimsDescription=(((train OR trains) AND (rail* OR track*)) OR railway* OR railroad* OR tramway* OR tram OR track_bound* OR (track OR tracks OR rail) SEQ2 vehicle* OR track_side* OR locomotive*) OR Tag=("EconSight Technology Fields\M1.3.7. Railroad & Tramway") OR IPC=(B61) OR CPC=(B60Y2200/30, B61, Y02T 30, Y10S 104, Y10S 505/902, Y10T 137/6866)) AND NOT (TitleAbstractClaims=(railway crossing OR power train*) AND NOT (TitleAbstractClaims=(train OR trains OR railway* OR railroad* OR tramway* OR tram OR track_bound* OR (track OR tracks OR rail) SEQ2 vehicle* OR track_side* OR locomotive*)))

Fuel cells in ships

((Tag=("*WIPO FC Study\FCTransport All (Cleaned)*") AND (TitleAbstractClaimsDescription=(ship OR ships OR ship_building* OR marine OR maritim OR ocean* OR water_borne* OR sub_sea OR sub_marine* OR tanker OR sea transport* OR boat OR shipping OR ship_building* OR marine OR maritim OR ocean* OR water_borne* OR water_vehicle* OR tanker OR sea transport* OR boat OR shipping OR marine) OR Tag=("EconSight Technology Fields\M1.5.4. Ships, Maritim Waterways & Offshore») OR IPC=(B63) OR CPC=(B63, Y02T 70, Y02T 90/38, Y02T 90/46)) OR CPC=(Y02T 90/38, Y02T 90/46)))

Fuel cells in special vehicles

Tag=("*WIPO FC Study\FCTransport All (Cleaned)*") AND (TitleAbstractClaimsDescription=((forklift* OR fork_lift* OR (airport* OR harbour* OR load SEQ2 transporting OR tow SEQ2 bar) NEAR3 vehicle* OR aircraft NEAR3 (tug* OR tow*)) OR crane* OR bulldozer* OR grader* OR excavator* OR tractor* OR bagger* OR dredger*) OR Tag=("EconSight Technology Fields\6P.3.25. Fork-Lift, Airport Tugs, Harbour Vehicle", "EconSight Technology Fields\6P.3.8. Heavy Equipment, Drilling, Mining, Special Transport") OR IPC=(B66F 9/06, E02F) OR CPC=(B66F 9/06, B66F 17/003, E02F))

Fuel cells, broad

(((TitleAbstractClaims=(fuel* SEQ2 cell* OR fuel_cell* OR bipolar NEAR3 plate*) OR IPC=(B60W 10/28, H01M 4/86, H01M 4/88, H01M 4/90, H01M 8/00, H01M 8/02, H01M 8/04, H01M 8/06, H01M 8/08, H01M 8/10, H01M 8/12, H01M 8/14, H01M 8/16, H01M 8/18, H01M 8/20, H01M 8/22, H01M 8/24) OR CPC=(B32B2457/18, B60K 6/32, B60L 3/0053, B60L 11/1881, B60L 50/70, B60L 50/71, B60L 50/72, B60L 50/75, B60L 53/54, B60L 58/30, B60L 58/40, B60L2230/28, B60W 10/28, B60W2510/28, B60W2710/28, B60Y2400/202, B63H2021/003, B64D2041/005, B64G 1/423, B65H2801/72, C01B2203/066, C10L2270/06, F01N2240/32, F17C2270/0184, F17C2270/0763, F24D2200/19, F24H2240/10, F28D2021/0043, G05B2219/2668, H01J 3/388, H01M 4/86, H01M 4/88, H01M 4/90, H01M 8, H01M 8/00, H01M 8/02, H01M 8/04, H01M 8/06, H01M 8/0618, H01M 8/08, H01M 8/083, H01M 8/086, H01M 8/10, H01M 8/1011, H01M 8/1018, H01M 8/1023, H01M 8/1025, H01M 8/1027, H01M 8/103, H01M 8/1032, H01M 8/1034, H01M 8/1037, H01M 8/1039, H01M 8/1041, H01M 8/1058, H01M 8/1065, H01M 8/1067, H01M 8/1069, H01M 8/12, H01M 8/1246, H01M 8/1253, H01M 8/14, H01M 8/16, H01M 8/18, H01M 8/20, H01M 8/22, H01M 8/24, H01M 8/241, H01M 8/2425, H01M 12/04, H01M 12/08, H01M 16/003, H01M2008, H01M2008/128, H01M2008/1293, H01M2008/147, H01M2250, H02J 3/387, H02J2001/004, Y02B 90/10, Y02E 60/50, Y02E 60/521, Y02E 60/523, Y02E 60/525, Y02E 60/526, Y02E 70/20, Y02P 70/56, Y02P 90/40, Y02T 90/30, Y02T 90/32, Y02T 90/34, Y02T 90/38, Y02T 90/40, Y02T 90/46, Y02W 30/86, Y10S 429/90, Y10S 429/901, Y10S 903/908, Y10S 903/944) OR FTerm=(2F129/DD50, 3D202/BB49, 3D202/EE06, 3D203/AA34, 3D203/DB11, 3D235/CC22, 3L211/AA13, 4G069/CC32, 4G169/CC32, 4H060/GG02, 5G003/AA05, 5G503/AA05, 5H017/AA10, 5H018/AA01, 5H026, 5H027, 5H115/PI18, 5H125/AC07, 5H125/BD01, 5H125/EE32, 5H125/FF08)) OR TechnologyClusters=("Electronics > Electric power > Cell stack > Bipolar plate", "Electronics > Electric power > Fuel battery > Acceptable electrochemical reaction", "Electronics > Electric power > Fuel battery > Hydrogen fuel", "Electronics > Electric power > Fuel battery > Portable disposable fuel-battery", "Electronics > Electric power > Fuel supply > Air supply", "Electronics > Electric power > Fuel supply > Condensation capacity", "Electronics > Electric power > Fuel supply > Fuel cartridge", "Electronics > Electric power > Fuel supply > Fuel tank", “Electronics > Electric power > Fuel supply > Oxide fuel cell”, “Electronics > Electric power > Fuel supply > Reformer”, “Electronics > Electric power > Fuel supply > Reforming”, “Machines > Engines > Reforming > Fuel cell fc”, “Physics > Chemical processing > Reformer > Fuel cell”, “Transportation > Automotive > Fuel supply > Hydrogen”, “Transportation > Automotive > Spoiler > Fuel cell stack”)) OR Tag=(“EconSight Technology Fields\2E.4.13. SOFC Fuel Cells”, “EconSight Technology Fields\2E.4.14. DMFC, DAFC, Direct or Reforming Fuel Cell”, “EconSight Technology Fields\2E.4.15. AMFC Alkaline Membrane Fuel Cells”, “EconSight Technology Fields\2E.4.16. PAFC Phosphoric Acid Fuel Cells”, “EconSight Technology Fields\2E.4.17. MCFC Molten Carbonate Fuel Cells”, “EconSight Technology Fields\2E.4.7. PEM Fuel Cells”, “EconSight Technology Fields\2E.4.9. Fuel Cell Manufacturing, Stacking”)) OR (IPC=(B60L 50/60, B60L 50/70, B60L 50/75, H01M, H01M 4/137) OR CPC=(H01M, H01M 4/137, H01M 4/242)) AND TitleAbstractClaims=(fuel NEAR3 cell* OR Fuel_cell*)

Polymer electrolyte (or proton exchange) membrane (PEM)/anion exchange membrane (AEM) fuel cells

((IPC=(H01M 8/1018, H01M 8/1023, H01M 8/1025, H01M 8/1027, H01M 8/103, H01M 8/1032, H01M 8/1034, H01M 8/1037, H01M 8/1039, H01M 8/1041, H01M 8/1058, H01M 8/1065, H01M 8/1067, H01M 8/1069) OR CPC=(H01M 8/1018, H01M 8/1023, H01M 8/1025, H01M 8/1027, H01M 8/103, H01M 8/1032, H01M 8/1034, H01M 8/1037, H01M 8/1039, H01M 8/1041, H01M 8/1058, H01M 8/1065, H01M 8/1067, H01M 8/1069, H01M2008/1095, Y02E 60/521)) AND Tag=(“*Fuel Cell, broad*”) OR ((CPC=(H01M 8/10) OR IPC=(H01M 8/10) OR FTerm=(5H026/AA06, 5H126/BB06)) AND TitleAbstractClaimsDescription=((((anion OR Proton) NEAR2 (conduct* OR exchange) NEAR2 Membrane) NEAR5 (polymer* OR MEA OR AEM) OR PEM OR HT_PEM OR NT_PEM OR LT_PEM OR MEA OR AEM OR (polymer NEAR2 electrolyt*)) NEAR9 (fuel_cell? OR FC OR stack) OR PEMFC OR DMFC OR (Methanol NEAR3 Fuel Cell*)))) OR TitleAbstractClaims=(((anion OR Proton) NEAR2 (conduct* OR exchange) NEAR2 Membrane) NEAR5 (polymer* OR MEA OR AEM) OR (PEM OR HT_PEM OR LT_PEM OR NT_PEM OR (polymer NEAR2 electrolyt*)) NEAR3 (fuel_cell? OR stack OR MEA) OR PEMFC)

Direct methanol (DM)/direct ammonia (DA)/reformer fuel cells

(((IPC=(H01M 8/06) OR CPC=(H01M 8/06)) AND TitleAbstractClaims=(DMFC OR DAFC OR (reform* OR Direct OR FC OR Fuel Cell OR autothermal) NEAR3 (methanol* OR ethanol* OR alcohol* OR ammonia OR nh3))) OR IPC=(H01M 8/1011) OR CPC=(H01M 8/0618, H01M 8/1011, Y02E 60/523)) OR (Tag=(“ *Fuel Cell, broad* “, “*Fuel Cell Manufacturing, Stacking*”) AND TitleAbstractClaims=(DMFC OR DAFC OR (reform* OR Direct OR FC OR Fuel Cell OR autothermal) NEAR3 (methanol* OR ethanol* OR alcohol* OR ammonia OR nh3) OR ((iquid NEAR3 (ammonia OR nh3)) OR methanol* OR ethanol* OR alcohol*) NEAR9 (fuel cell* OR reform* OR autothermal*)))

Solid oxide fuel cells (SOFCs)

(TitleAbstractClaims=((SOFC OR solide SEQ2 oxid* OR ((zro2 OR y2o3 OR ceo2 OR la2o3 OR mgo OR tio2 OR solid* OR ceramic* OR cermet* OR chromit* OR Ni_YSZ* OR yttria OR titanium_oxid* OR magnesium_oxid* OR cerium_oxid* OR zirconia* OR oxide) NEAR3 (membran* OR anode*)) NEAR5 (fuel_cell OR FC))) OR CPCOriginal=(H01M 8/1206, H01M 8/1213, H01M 8/1231, H01M 8/1233, H01M 8/124, H01M 8/1246, H01M 8/1253, H01M 8/1286, H01M 8/2415, H01M 8/2418, H01M 8/242, H01M 8/2425, H01M 8/2428, H01M 8/243, H01M 8/2432, H01M 8/2435, H01M 8/244, H01M2008/128, H01M2008/1293) OR ((CPC=(H01M 8/10) OR IPC=(H01M 8/10) OR FTerm=(5H026/AA06, 5H126/BB06)) AND TitleAbstractClaims=((SOFC OR solide SEQ2 oxid* OR ((zro2 OR y2o3 OR ceo2 OR la2o3 OR mgo OR tio2 OR solid* OR ceramic* OR cermet* OR chromit* OR Ni_YSZ* OR yttria OR titanium_oxid* OR magnesium_oxid* OR cerium_oxid* OR zirconia* OR oxide) NEAR3 (membran* OR anode*)) NEAR7 (fuel_cell OR FC)))))

Alkali membrane fuel cells (AMFCs)

((TitleAbstractClaims=((alkali* OR KOH OR NaOh) NEAR3 Fuel_Cell* OR (alkali* OR KOH OR NaOh) NEAR5 membran* OR (conduct* NEAR3 (alkali* OR hydroxyl* OR OH-) NEAR3 (ion OR ions)) NEAR5 membran* OR AMFC OR Alkaline Membrane Fuel Cell* OR Alkaline Polymer Electrolyte Membrane

Fuel Cell*) OR CPC=(H01M2300/0002, H01M2300/0014)) AND Tag=(" *Fuel Cell, broad* ") OR IPC=(H01M 8/083) OR CPC=(H01M 8/083)) AND NOT (Tag=("EconSight Technology Fields\2E.4.6. Lithium Batteries", "EconSight Technology Fields\2E.4.6.1. Lithium Iron Phosphate Cathode/ Batteries") OR TitleAbstractClaims=((secondary* OR rechargeable* OR redox_flow*) NEAR3 (battery OR batteries OR accumulator*) OR electrolysis NEAR3 (alkali* OR chlor_alkali* OR cell*)))

Phosphoric acid fuel cells (PAFCs)

((TitleAbstractClaims=((phosphoric_acid* OR h3po4 OR phoshor* NEAR3 acid* OR (teflon* OR ptfe) NEAR3 membran*)) OR CPC=(H01M2300/0005, H01M2300/0008)) AND Tag=(" *Fuel Cell, broad* ") OR IPC=(H01M 8/086) OR CPC=(H01M 8/086) OR TitleAbstractClaims=(phosphoric acid fuel cell*)) AND NOT (Tag=("EconSight Technology Fields\2E.4.6. Lithium Batteries", "EconSight Technology Fields\2E.4.6.1. Lithium Iron Phosphate Cathode/Batteries") OR TitleAbstractClaims=((secondary* OR rechargeable* OR redox_flow* OR liquid flow) NEAR3 (battery OR batteries OR accumulator*)))

Molten carbonate fuel cells (MCFCs)

((TitleAbstractClaims=((molten OR melt*) NEAR3 carbonat* OR MCFC OR ((lithium OR potassium OR sodium) NEAR3 carbonat*) NEAR5 (elektrolyt* OR fuel_cell*)) AND Tag=(" *Fuel Cell, broad* ") OR CPC=(H01M2008/147, H01M2300/0048, H01M2300/0051)) OR TitleAbstractClaims=(((molten OR melt*) NEAR3 carbonat* OR MCFC OR (lithium OR potassium OR sodium) NEAR3 carbonat*) NEAR5 (fuel_Cell*))) AND NOT (Tag=("EconSight Technology Fields\2E.4.6. Lithium Batteries", "EconSight Technology Fields\2E.4.6.1. Lithium Iron Phosphate Cathode/Batteries") OR TitleAbstractClaims=((secondary* OR rechargeable* OR redox_flow* OR liquid flow) NEAR3 (battery OR batteries OR accumulator*)))

Fuel cell manufacturing, stacking

(TitleAbstractClaims=(fuel_Cell* NEAR3 (stack OR stacks OR stacking OR manufactur*)) OR (IPC=(H01M 8/00, H01M 8/02, H01M 8/04, H01M 8/06, H01M 8/08, H01M 8/10, H01M 8/12, H01M 8/14, H01M 8/20, H01M 8/22, H01M 8/24) OR CPC=(B65H2801/72, H01M 8/00, H01M 8/02, H01M 8/04, H01M 8/06, H01M 8/08, H01M 8/10, H01M 8/12, H01M 8/14, H01M 8/22, H01M 8/24, Y02E 60/50) OR FTerm=(5H026, 5H027))) AND (TitleAbstractClaimsDescription=(process* OR manufactur* OR production* OR producing) OR Description=((stacking OR stack) NEAR3 (process* OR manufactur* OR production* OR producing)) OR CPCOriginal=(H01M 8, H01M 8/00, Y02P 70/56))

Fuel cell recycling

(Tag=("*SOFC Fuel Cells*", "*DMFC, DAFC, Direct or Reforming Fuel Cell*", "*AMFC Alkaline Membrane Fuel Cells*", "*PAFC Phosphoric Acid Fuel Cells*", "*MCFC Molten Carbonate Fuel Cells*", "*Fuel Cell, broad*", "*PEM Fuel Cells*", "*Fuel Cell Manufacturing, Stacking*", "*Fuel Cells in Transport*") AND (Tag=("EconSight Technology Fields\E8.3.3. Recycling and Reuse", "EconSight Technology Fields\E8.3.6. Plastic, Glass, Paper, Electronics & Consumer Waste Recycling") OR CPC=(Y02W 30/84, Y02W 30/86) OR TitleAbstractClaims=(((upcycl* OR Recycl* OR recover*) NEAR3 (fuel SEQ2 cell* OR bipolar SEQ2 plate* OR gas diffusion electrode*)) AND (shred* OR brake* OR crush* OR demantle* OR dismantle* OR leach* OR ((metal* OR catalyst* OR noble* OR valuable*) NEAR3 extract*)))) OR CPC=(Y02W 30/86))

Electric vehicles

Part 1

(CPC=(B60H 1/00392, B60L, B60L 11, B60L 50, B60Y2200/91, F16H2200/0021, Y02T 10/64, Y02T 10/70, Y02T 10/7038, Y02T 10/7072, Y02T 10/72, Y02T 90/10, Y02T 90/34) OR FTerm=(2F129/DD49, 2G014/AB23, 2G014/AB35, 2G036/BA10, 3D032/GG15, 3D131/BB02, 3D203/AA31, 3D203/AA34, 3D241/CA08, 3D246/AA08, 3D333/CB09, 3D333/CB10, 3J063/AA04, 3J067/GA16, 3L211/AA11, 3L211/AA13, 5E123/AA23, 5G503/FA06, 5H040/AS07, 5H043/AA13, 5H127/FF, 5H501/AA01, 5H505/ AA19, 5H550/AA01, 5H560/AA08, 5H570/AA01, 5H576/AA01, 5H770/BA02) OR IPC=(B60L 11, B60L 11/16, B60L 11/18, B60L 50/70, B60L 50/71, B60L 50/72, B60L 53/16, B60L 53/18, B60L 58/00))

Part2
(TechnologyClusters=("Electronics > Electric power > Energy storage > Electric vehicle", "Information > Administration > Reservation > Electric vehicle charging", "Transportation > Automotive > Electric vehicle", "Transportation > Automotive > Fuel cell vehicle", "Transportation > Automotive > Lifting > Electrically-powered autonomous vehicle", "Transportation > Cycles > Electric bicycle", "Transportation > Cycles > Electric vehicle", "Transportation > Cycles > Vehicle > Electric balance car") OR (((IPC=(B60L, B60L 50, B60R 16, B60W, B62D) OR CPC=(B60, B60G2300/50, B60L, B60L 50, B60R 16, B60W, B60Y2200/90, B62D, H02J2310/48, Y02T 10, Y02T 10/62, Y02T 90/169, Y04S 10/126, Y04S 30/10) OR Tag=("EconSight Technology Fields\ M1.2.1. Battery Charger for Road Vehicles",)) AND TitleAbstractClaims=(((only OR battery OR all OR pure) SEQ3 electric NEAR5 (vehicle* OR car OR automotiv* OR automobil* OR Road_going OR passenger_vehicle*) OR BEV OR PHEV OR FCEV)))))

Part 1 or 2 = *Electric Vehicles*

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World Intellectual Property Organization
34, chemin des Colombettes
P.O. Box 18
CH-1211 Geneva 20
Switzerland

Tel: +41 22 338 91 11
Fax: +41 22 733 54 28

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External Offices visit:
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